Electronic Devices & Networks Annex
EDNA

Total Energy Model for Connected Devices

JUNE 2019

Total Energy Model for Connected Devices

Report Prepared for IEA 4E EDNA

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The Technology Collaboration Programme on Energy Efficient End-Use Equipment (4E TCP), has been supporting governments to co-ordinate effective energy efficiency policies since 2008.

Fifteen countries have joined together under the 4E TCP platform to exchange technical and policy information focused on increasing the production and trade in efficient end-use equipment. However, the 4E TCP is more than a forum for sharing information: it pools resources and expertise on a wide a range of projects designed to meet the policy needs of participating governments. Members of 4E find this an efficient use of scarce funds, which results in outcomes that are far more comprehensive and authoritative than can be achieved by individual jurisdictions.

The 4E TCP is established under the auspices of the International Energy Agency (IEA) as a functionally and legally autonomous body.

Current members of 4E TCP are: Australia, Austria, Canada, China, Denmark, the European Commission, France, Japan, Korea, Netherlands, New Zealand, Switzerland, Sweden, UK and USA.

Further information on the 4E TCP is available from: **www.iea-4e.org**

The EDNA Annex (Electronic Devices and Networks Annex) of the 4E TCP is focussed on a horizontal subset of energy using equipment and systems - those which are able to be connected via a communications network. The objective of EDNA is to provide technical analysis and policy guidance to members and other governments aimed at improving the energy efficiency of connected devices and the systems in which they operate.

EDNA is focussed on the energy consumption of network connected devices, on the increased energy consumption that results from devices becoming network connected, and on system energy efficiency: the optimal operation of systems of devices to save energy (aka intelligent efficiency) including providing other energy benefits such as demand response.

Further information on EDNA is available at: **http://edna.iea-4e.org**

This report was commissioned by the EDNA Annex of the 4E TCP. It was authored by Paul Ryan of EnergyConsult Pty Ltd, Terence Smith of Mississippi Consulting Pty Ltd and Anson Wu of Hansheng Ltd. The views, conclusions and recommendations are solely those of the authors and do not state or reflect those of EDNA, the 4E TCP or its member countries.

Electronic Devices & Networks Annex
EDNA

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Glossary

Access Network	An Access Network ist he Internet service provider's network providing the connection between the core and edge networks.
AEC	Annual Energy Consumption is the product of power consumed and time in hours over a year measured in Watthours/year.
BLE	Bluetooth Low Energy (BLE) is the ultra-low power consumption version of the Bluetooth.
Core Network	A Core Network is a network or set of networks at the centre of the Internet consisting of IP service providers' networks.
CSTB	Complex Set-Top box
DC	Data Centre
Downstream	In the scope of this study, downstream energy use includes all energy use of edge devices and LAN equipment.
DVB-T/T2	DVB-T is the original Digital Video Broadcasting standard for terrestrial television developed by the Europe based DVB Project. DVB-T2 is the second-generation terrestrial standard.
Edge Network	An Edge Network is a mobile wireless broadband, WLAN or LAN on the periphery of the Internet or other heterogenous netwotk.
EEE	Energy-Efficient Ethernet (IEEE 802.3az) is an amendment to the Ethernet standard defining a Low Power Idle mode which the network can enter when there is no data traffic.
HbbTV	Hybrid broadcast broadband TV is an industry based standard fort he carriage of servcie descriptors in a DVB-T/T2 transport stream to enable access to video content on a Smart TV's or STB IP network port.
ICT	Information and Communications Technology is the term used by the ITU-T to what was previously referred to as Information Technology (IT).
IP	Internet Protocol (IP) defines the structure of data packet envelopes sent over the Internet from one computer to another each identifed by a unique address.
ITU	International Telecommunications Union, the United Nations body responsible for international telecommunications and radiocommunications standards development.
LAN	Local Area Network
LoRaWAN	A proprietary Low Power WAN using unlicensed bands based on the LoRa™ physical layer patented by the Semtech Corporation.
M2M	Machine-to-Machine is a wireless communication system connecting devices such as sensors and computers in an IoT ecosystem.
NB-IoT	Narrowband Internet of Things is a cellular wireless communications technology used in the IoT.
Network Active	Network Active is a condition in which a device is communicating with another device on a network.
Network Standby	Network Standby is a condition in which a device is in a low power mode and not communicating with another device on a network but from which it may be woken by another device.
Over the Top (OTT)	Over the Top describes a service delivered over a network shared with other services. It is commonly used to describe an Internet video streaming service.
Router	A router is a device which directs data traffic from one network to another in ordert to deliver it tot he intended destination.
Smart TV	A Smart TV is to television what Smart phones is to moble telephony, which ist o say it provides access to video content either related to or in addition to that accessed by normal broadacast channels.
TWh	A measure of electrical energy, 10^{12} Watt-hours, where an energy consumption of 1 Watt-hour is equivalent to a power consumption one Watt for one hour.
UEC	Unit Energy Consumption is product of the power consumed and time measured in hours, the units are thus Wh or kWh.
Upstream	In the scope of this study, upstream energy use includes all energy use of DC and WAN, including the access network.

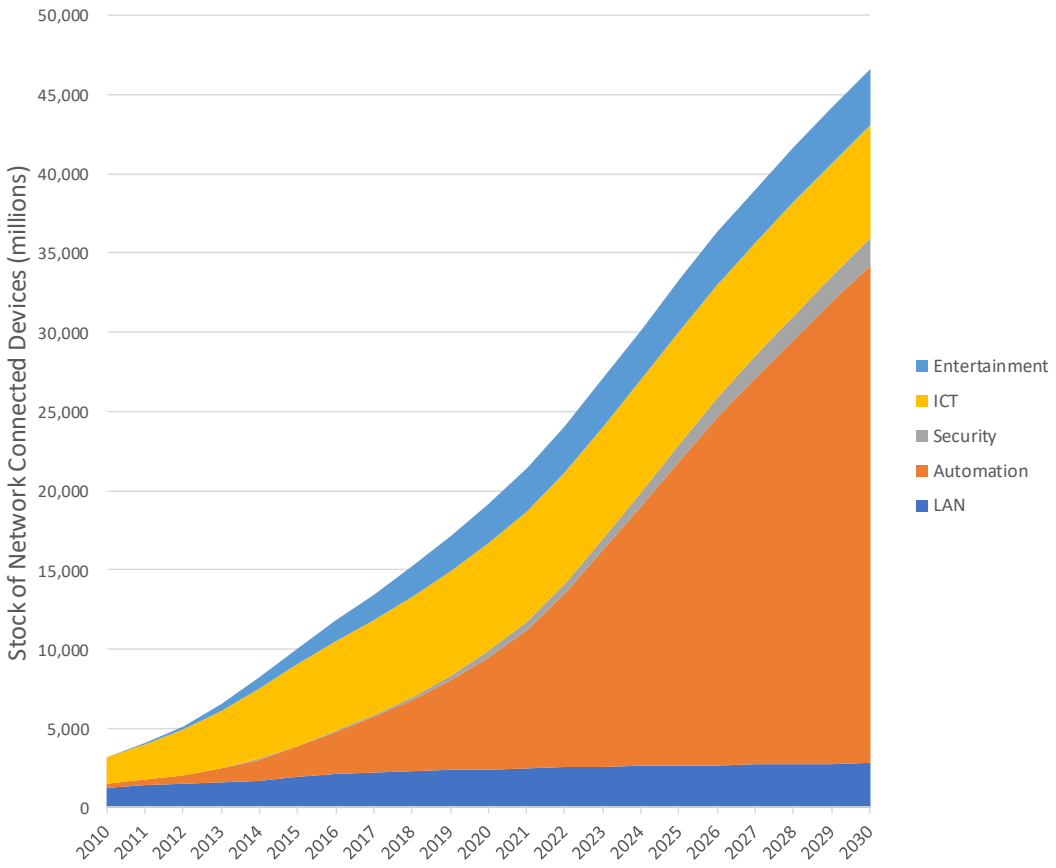
Voice Assistant	A Voice Assistant is a connected device which responds to voice commands which may be intended to control household equipment such as lighting, heating/cooling, audiovisual equipment, act as a VoIP device or respond to general interest queries.
W	The symbol for Watts, a measure for power.
WAN	A Wide Area Network (WAN) is a computer (or other connected device) network spanning a region, country or the globe connecting a number of LANs comprising a diverse range of telecommunications networks.
WLAN	A Wireless Local Area Network (WLAN) is almost exclusively a IEEE 802.11 (Wi-Fi) network.
WPAN	A Wireless Personal Area Network (WPAN) is a short range (<10 m) wireless device-to-device (D2D) network. WPANs include Bluetooth and Zigbee.

Executive Summary

Network related energy consumption by connected devices is a growing energy use in this highly connected world. Forecasts of the number of connected devices (also often referred to as the Internet of Things -IoT) range from 20 billion (Gartner Inc, 2017) to 50 billion (Juniper Research, 2018) by the early 2020's. Devices connected to the network include a wide range of technologies and equipment, such as TVs, mobile phones, sensors, lighting, thermostats, voice assistants, speakers, video cameras, etc. Some of these are new technologies, while many are existing types of appliances and equipment gaining a network connection.

The objective of this study is to develop a quantitative model of the "total energy use" of connected devices, globally. This report (and model) aims to quantify the total additional energy that results from devices becoming connected to a communications network. The Total Energy Model (TEM) is developed as a flexible tool, which can be updated as additional data becomes available. The purpose of the model is to provide a reputable source of energy use information for connected devices for use by policy makers. The TEM projects the stock of all network-connected devices to increase from an estimated 15 billion in 2018 to 46 billion in 2030, as shown in Figure ES1.

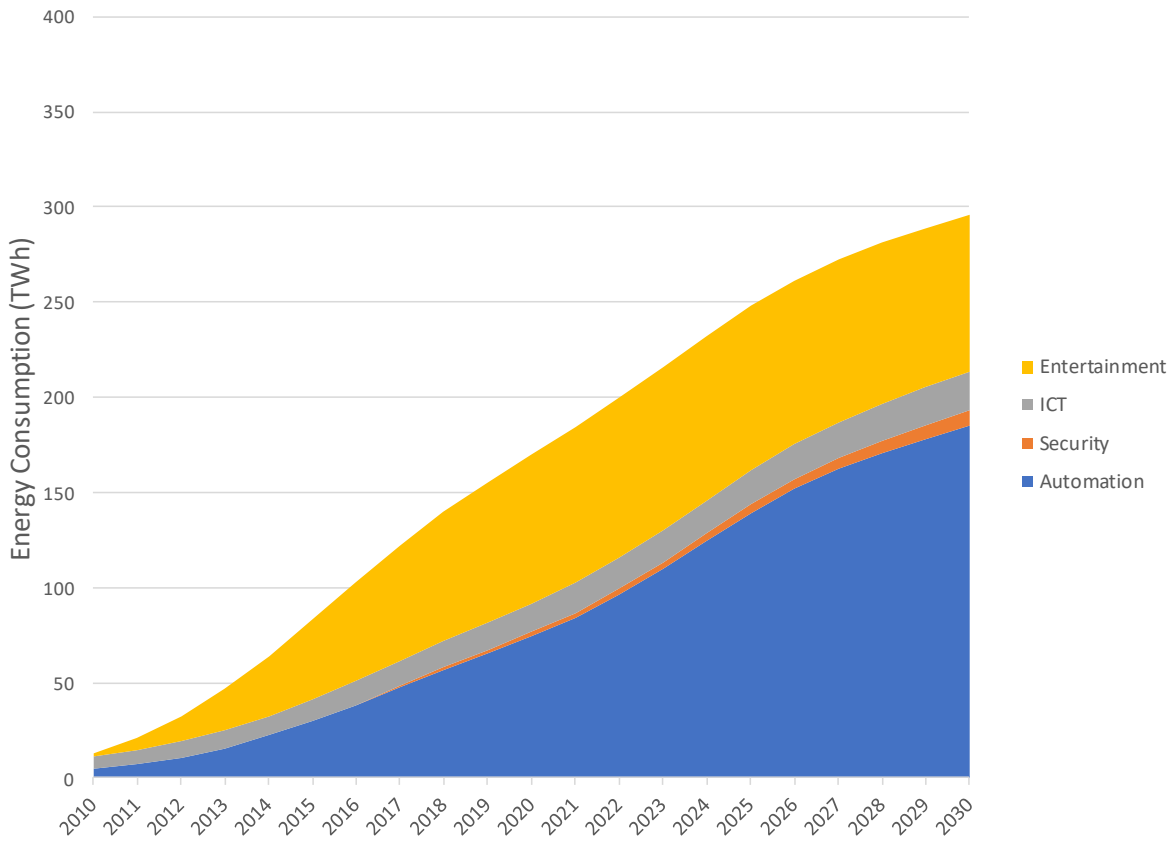
Figure ES1: Stock of network-connected devices by category 2010 – 2030



The TEM calculates the network-connected energy consumption of devices due to being connected to a communications network. The scope of energy included is only additional energy use of products that *results from devices becoming connected to a communications network.* This includes all the energy use of LAN equipment and the network-connected energy use of edge devices, such as smart thermostats, voice assistants, connected speakers and IP video cameras. The network-connected or additional energy use of appliances due to being connected to a network is also included, however their main function energy use is not included (i.e., the network standby energy consumption of a smart TV is included, but the TV operational energy use is not). The estimated network energy consumption is also separated into energy use in the network active condition and network standby condition. In addition, the "upstream" energy impacts that occur as a result of connected devices, i.e. in wide area networks (WAN) and data centres (DC), is also estimated and attributed to each devices type.

The network standby energy consumption of all devices is projected to double from 2018 to 2030. This is largely a result of the increasing installations of entertainment and automation devices, and the type of network connections that are used, as shown in Figure ES2.

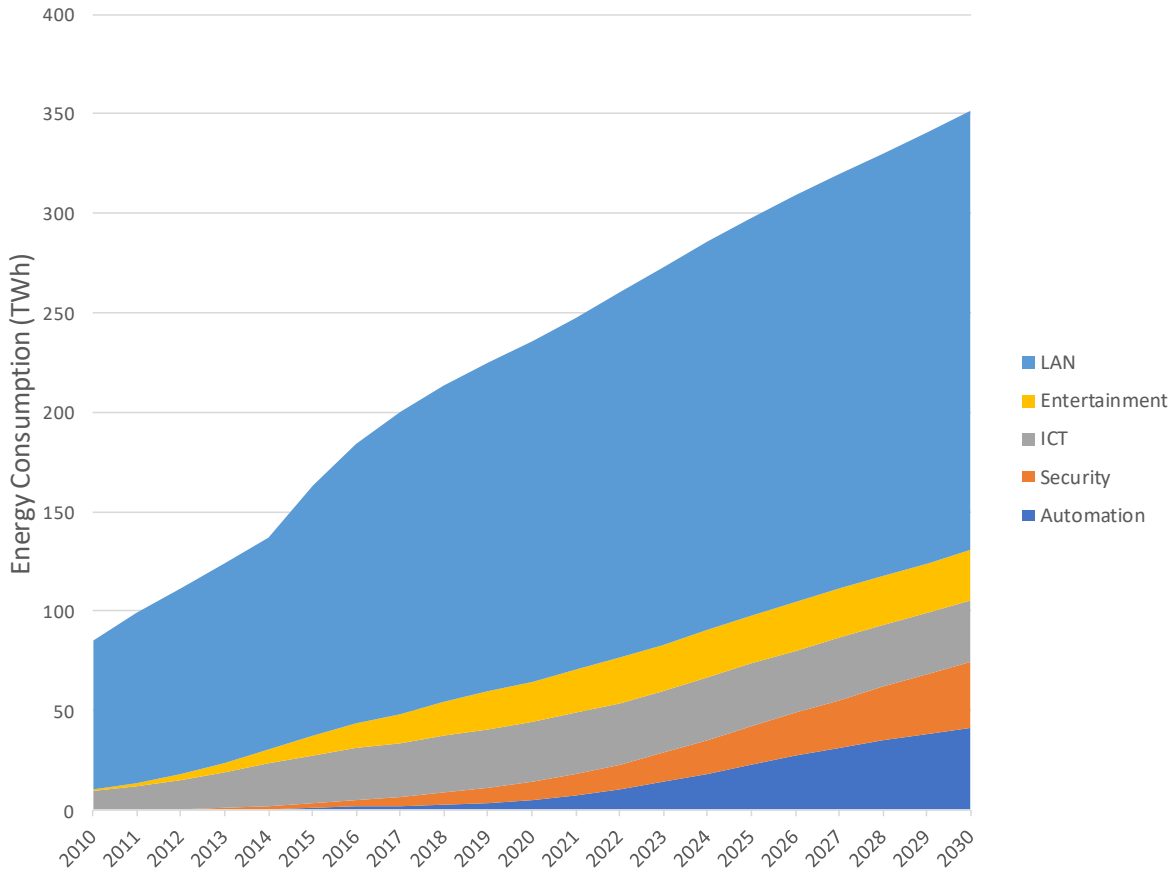
Figure ES2: Network standby energy consumption of devices by category 2010 – 2030



The majority of network active state energy use is attributed to LAN equipment, as shown in Figure ES3. This network active state energy use is increasing due to the increasing number of internet

connections and also an increasing power consumption per device, due to more functional devices (such as integrated access devices, which combine WAN connections/modems with routers and access points).

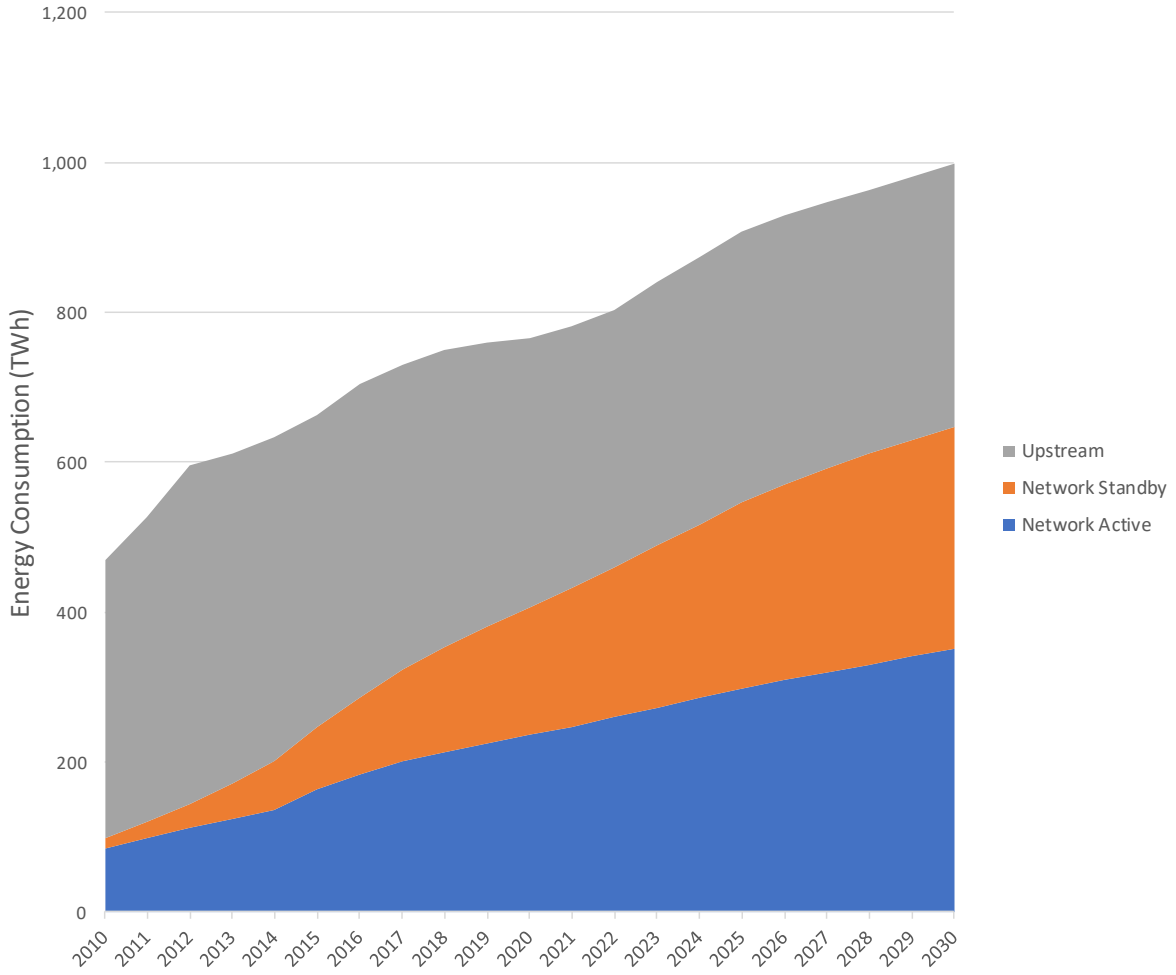
Figure ES3: Network active energy consumption of devices by category 2010 – 2030



The total energy consumption due to devices becoming connected to the network is shown in Figure ES4 and includes three main components, as follows:

- Upstream energy use of the communications and data networks and the data centres – which is increasing till 2012 and slowly decreasing
- Network standby energy use of the edge equipment, which is rapidly increasing over the period as more devices are connected
- Network active energy use of the edge equipment and LAN equipment, which is also increasing over the period

Figure ES4: Network-connected energy consumption by component 2010 -2030



1 Introduction

1.1 Background

Network related energy consumption by connected devices is a growing energy use in this highly connected world. Forecasts of the number of connected devices (also often referred to as the Internet of Things -IoT) range from 20 billion (Gartner Inc, 2017) to 50 billion (Juniper Research, 2018) by the early 2020's. Devices connected to the network include a wide range of technologies and equipment, such as TVs, mobile phones, sensors, lighting, thermostats, voice assistants, audio speakers, video cameras, etc. Some of these are new technologies, while many are existing types of appliances and equipment gaining a network connection.

Although network-connected devices can substantially reduce energy wastage of appliances and equipment by controlling and optimising the systems used to deliver energy services, there is often additional energy used to create, maintain and communicate data over the network. To ensure that these devices use a minimal amount of energy to stay connected, 4E's Electronic Devices and Networks Annex (EDNA) works to align government policies in this area and keep participating countries informed as markets for network-connected devices develop.

Devices use energy to communicate over the network, as well as for performing their other functions. Energy is also used to send/receive data over the wider area network and by the data centres that process this data. The additional energy use that results from devices becoming connected to a communications network is the key focus of this study, so energy use is separated into the network-connected device associated energy use and the upstream energy use to transmit and process the data.

1.2 Objective

The objective of this study is to develop a quantitative model of the "total energy use" of connected devices, globally. This report (and model) aims to quantify the total additional energy that results from devices becoming connected to a communications network. The Total Energy Model (TEM) is developed as a flexible tool, which can be updated as additional data becomes available. The purpose of the model is to provide a reputable source of energy use information for connected devices for use by policy makers.

1.3 Definitions

The key definitions used in this study are described in the following section, 2. Scope of Study

2 Scope of Study

The aim of this modelling is to quantify the total additional energy use of network-connected devices, including estimating the "upstream" energy impacts that occur as a result of connected devices, i.e. in local area networks (LANs), wide area networks (WANs) and data centres (DCs). To quantify the upstream energy use of the WANs and DCs, the TEM utilises the quantitative data from the modelling undertaken in the EDNA study *Intelligent Energy Efficiency Data Centres & Wide Area Networks*,(EDNA, 2019).

There are a number of key definitions that guide the scope and content of the TEM relating to the connected devices and the LAN, including:

- Definitions of network-connected devices
- Defining what is "additional" energy use
- Defining the conditions of energy use and what energy use is related to "network-connected"

These key definitions are described in the following sections.

2.1 Scope of connected devices

The IEA has used the following definition for connected devices in the scope of products included within the *Digitalisation & Energy* (IEA, 2017) report:

> *In discussing the energy use of connected devices (as a segment of ICT), it is helpful to distinguish between two types of connected devices: "electronic edge devices", whose primary function is data storage/use, such as laptops and smartphones, and "other edge devices", whose primary functions are not data-related, such as networked kitchen appliances and cars. Only data-related energy use is considered in this section, specifically energy use by "electronic edge devices" as well as any networked standby energy use of "other edge devices" (p 112).*

These definitions of devices are used to guide the scope of devices included in the TEM. However, the model has also calculated the energy use of LAN equipment as these are considered to be within the scope of the model boundary and sufficient data is available to estimate the energy use. The LAN equipment is separately defined as LAN devices. All equipment and energy use that is upstream of the LAN is considered to be "Upstream" energy use. The upstream equipment includes the WAN and the Core network, as well the data centres providing processing and data storage.

Based on these scope definitions, the modelling distinguishes the network-connected energy use into the following classifications

- Edge devices (both electronic and other edge devices)
- LAN equipment
- Upstream (WAN and DC equipment)

2.2 Scope of network-connected energy use

A major factor for defining the scope of the modelled energy use is defining the component of energy use that is additional due to being connected to a network. This definition is interpreted as meaning data-related energy use as defined by the IEA *Digitalisation & Energy* (IEA, 2017) report.

In general, the energy use states are considered under the definition of "additional" in relation to the total additional energy use of network-connected devices, by category, are as follows:

- Electronic Edge Device: All modes/conditions of energy use of connected edge devices.
- Other Edge Devices: All modes/conditions of energy use of connected devices that exists to service the device functions while connected to the network, where this is additional to the normal functioning of the device or service that is being performed.
- LAN Equipment: All modes/conditions of energy use of LAN equipment is attributable to data services for connected edge devices.
- DC/WAN: Energy use by the DC/WANs that is attributable to the data services for connected edge devices.

A description of the energy use state that is considered in the scope of the TEM for each device is shown in Appendix A: TEM connected devices – calculations and assumptions. There are some exceptions to these guiding definitions, for instance, a laptop is an electronic edge device, but only the network-connected energy use is considered within the scope as additional energy use.

The additional energy use associated with the manufacture/disposal of the devices is not included in the modelling, although it is recognised that this component can be significant in terms of life cycle energy use in smaller (typically battery powered) devices like smart phones and tablets.

2.3 Definition of states of network-connected energy use

The network-connected energy use needs to be disaggregated to enable the TEM to inform policy makers of the potential benefits of policy options, which have to date been focused on network standby. In addition, it will be beneficial for energy efficiency policy analysis to provide the estimated total additional energy use attributable to connected devices, where *this results from devices becoming connected to a communications network*. To assist with this attribution, the following conditions are defined as described in earlier IEA studies (Harrington and Nordman, 2014; IEA, 2014):

- Network Active condition, which includes any state in which a device performs some function that requires interaction with a network
- Network Standby condition, which is a "Low power mode with network connectivity" and refers to states in which a device is not delivering its primary/secondary function(s) but retains the capability to resume applications via a network connection.

These two conditions are mutually exclusive. A device is either communicating over the network or is in a network standby condition. The energy use associated with these network conditions is the focus of this study. Other energy use may be occurring while these conditions are present, such as the energy use of a connected light. The network standby condition is present in the on-mode (because the light can be remotely controlled when providing light). For the vast majority of other edge devices (appliances, etc.), the energy use of the network interface and additional processing required to perform the network-connected functions is of interest, as this is additional to the energy use of the

device because to is connected to a network. In most cases off mode will not be relevant, as all connected devices will be connected most of the time.

The additional energy use of products that *results from devices becoming connected to a communications network* may be difficult in practice to measure and estimate. For instance, an IP Camera will have energy use associated with the camera and the network communications. To isolate the energy use of the network communications component would require estimates of the network communication power use, as this is not typically reported or measured. In practice, the entire energy usage of the device would need to be considered additional, as it would not be present without a network connection (for instance, an IP camera connected to the network as compared to a security camera wired to a recording device). This simplification assumes that all devices that can only perform their main function with a network connection would be considered "additional" in themselves, and hence all the energy use is additional in terms of the scope of the TEM.

The examples of particular applications and devices are shown in Table 1.

Table 1: Examples of energy use included in the scope of the TEM

Example Device/Area	Modes or Condition	Function Examples	Included TEM	Rationale
Video on Demand				
Smart TV	On mode	Streaming Video	No	Not additional to normal use
	Network Standby	To enable on demand streaming	Yes	Is required to be connected to stream video
	Network Active	Provide data control and transfer while streaming or main functions	Yes	Is required for data functions, assumed to be the same power demand as network standby condition.
Router (LAN)/modem/access point	Network Active	Conveying video for devices, routing data	Yes	All Additional energy use due to being connected
Home Automation				
Connected Light	On mode	Providing light	No	The energy use of the light is not additional
	Network standby/active	For control of the light	Yes	Additional network energy
Occupancy Sensor	Network standby/active	For control of light or other functions	Yes	All energy use is additional, as would not be present if it could not connect to the network
Gateway/Bridge	Network active	To connect devices/sensors to the IP network	Yes	All the energy use is additional, so that other connected devices can communicate

The network condition is identified and categorised within the TEM. The amount of energy attributed to some devices for the network on condition may be the entire energy use of the device or the proportion that is used for network communications. The estimated power use by condition has been assumed to be the same in many products for simplicity, as it is difficult to estimate the network active

energy use only applicable to the network-connected device if there are other main functions being performed.

Note that LAN equipment is also suitable to be included in policies targeting the reduction in network standby energy use, however, the TEM has currently attributed all LAN equipment energy use to the network active state[1].

The other key criteria in terms of the scope is the definition of "*communications network".* For this study, it is considered to mean digital data communications network with two-way (duplex) communications. It would include all public internet communications networks (fixed or wireless/satellite), LANs and many low power communications networks for IoT devices. This definition would also include private or isolated networks, such as for utility smart meters, transport control/monitoring, etc. Hence all devices connecting to these networks would be included. Decisions have been made in the following areas:

- Broadcast networks – Terrestrial TV broadcasting is generally one-way transmission communication; however, we understand that Regulation (EC) 801/2013 defines DVB-T terrestrial TV as a network, it only needs to be a means of sending a trigger to the TV. A DVB-T/T2 network supporting Hybrid Broadcast Broadband TV services is a duplex network, even though one direction is over-the-air and the other over the internet. The network port in this case would define the product category as within scope. The issue would be if a DVB-T is defined as a communications network, all TVs and modes of use would be included in the scope. It has been decided to exclude broadcast TV from the TEM.
- Cable/satellite TV communications networks – Complex STBs are included if they are connected to an IP network. STBs only connected to a broadcast communications network are not included as this not generally duplex communications.
- Military networks – as they are not easily identified and data on their operation is not usually available, they would be excluded.

The other issues that impact on the scope are related to the scope of the potential energy sources:

- The energy used for the production of the devices and equipment (embodied energy) is excluded.
- Mains powered devices, including those with a low voltage external power supply, are included.
- Rechargeable battery devices are included (as they will eventually draw energy from the grid).
- Non – rechargeable battery devices are excluded (their energy is embodied in their manufacture). However, the upstream data communication energy impacts of these devices are included.
- Solar powered or off-grid powered network infrastructure (mostly WANs) is included, as this is potentially becoming common in developing and remote regions.

[1] Although technically LAN equipment is capable of entering a networked standby condition, various reports state that network equipment (LAN equipment) does not have any low power mode that is relevant to network standby. See page 3 (Harrington and Nordman, 2014)

- Connected devices in cars are excluded – as they are not in the scope of EDNA and it is difficult to determine if the devices are power by the combustion engine or, in the case of electric cars, from the grid.

2.4 Timeframe for estimated historical, current and projected energy use

The TEM scope is to provide a current/historical and projected energy use of the connected devices and their upstream energy impacts, on a global basis. Input data is collected from historical values in most cases over the period up to 2016 or 2017, therefore 2017 represents the current estimated energy use, and the period 2010 to 2017 is historical energy use. The model uses projections from various sources or trends for the period 2018 to 2030, which represents the projected energy use. The data sources are not readily available post 2023 therefore projections to 2030 are highly uncertain with rapidly changing technologies and services.

3 Methodology

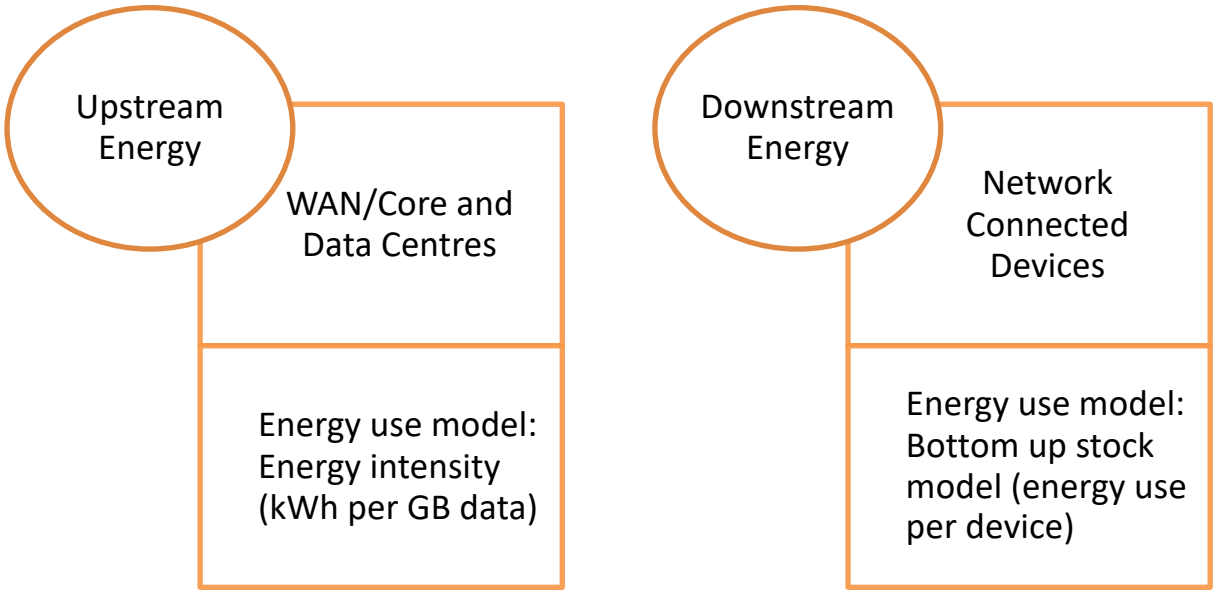
The Total Energy Model (TEM) calculates the network-connected energy use of devices by summing the individual energy use by condition for all the connected devices in the world and attributes the upstream energy use of the network (DC/WAN) to each device type. The approach taken in building the model varies with the model's component parts.

For the edge device and edge network equipment, a bottom-up product stock model of energy use using the engineering method (Sathaye and Sanstad, 2004), meaning that energy use is estimated at the device level, and summed to provide global energy consumption. The methodology requires many data relating to the sales, life and stock of equipment, combined with the energy use characteristics of the equipment, which all vary over time.

For the DC/WAN component, including access networks, the approach uses the specific energy intensity of DC/WAN equipment types per data traffic carried over the WAN. The upstream energy use is calculated according to the share of data attributed to various DC/WAN technology types of the total projected data traffic. The energy intensity (energy use per data transferred or network efficiency), the share attributed to each DC/WAN technology types and the total network traffic varies over time.

Finally, to attribute the upstream energy use to the edge devices, the estimated data consumption of network devices is used to proportion the upstream energy use to the connected device. The approach by component is shown in Figure 1.

Figure 1: TEM approach by component



The bottom-up approach for the calculating the network-connected energy use of edge devices and edge network equipment enables policy makers to explore the impacts of changes in equipment performance characteristics and stock of equipment. Using a similar approach for the DC/WAN

component of the model also ensures that changes in the network architecture of the WAN and efficiency of the DC are included in energy consumption forecasts.

3.1 TEM energy use calculations

3.1.1 Edge device and LAN equipment calculations

The TEM is designed to estimate the total network-connected energy consumption by device at the global level. The network-connected Annual Energy Consumption (AEC) for each type of device is the sum of the network-connected energy consumption of all devices installed and operating. The model uses a methodology similar to the residential sector activity equations of the Lawrence Berkeley National Laboratory, Bottom-Up Energy Analysis System or BUENAS model (McNeil *et al.*, 2012).

Network-connected energy use is calculated for each of the conditions described in the earlier section 2.2 Scope of network-connected energy use; which are the network active and network standby condition. The AEC equation is as follows:

$$AEC(y,c) = \sum_{age=0}^{30} Sales\ (y-age)\ \times UEC_c(\ y-age) \times Surv(age)$$

Where

AEC (y,c) = the Annual Energy Consumption in year *y* for condition *c*
Sales (y) = unit sales (shipments) in year *y*
UEC (y) = unit energy consumption (UEC) of units sold in year *y*
Surv (age) = probability of surviving to *age* years
Age = a period of up to 30 years

The UEC for each device and condition is calculated as follows:

$$UEC_c = Power_{\ c} \times Time_{\ c}$$

Where

Power = watts of network-connected load for condition *c*
Time = hours of time in condition *c*

The sales or shipments of devices is an input and stock of devices is calculated by the model. Where the sales are not available for a particular device type, the sales are derived from increases/decreases in stock and retirements. The type of calculations for deriving the sales for each device type is shown in Appendix A: Connected Devices Calculations, Sources and Assumptions.

3.1.2 Upstream energy use calculations

The upstream energy use is estimated for the DC/WAN component by using the energy intensity or energy consumed per byte of data transferred in the DC and WAN and the data transfer rate. The energy intensity and data transfer for the DC and WAN are separately determined for different architecture/equipment generations, as described in the EDNA report (EDNA, 2019). The DC energy intensity is disaggregated by IT equipment and infrastructure equipment, and by utilisation to ensure that underlying changes of efficiency and use are included in the model outputs.

3.1.3 Attribution of upstream energy to devices

To attribute the upstream energy use to the networked connected devices, the TEM uses the amount of data traffic generated/consumed by each device type to proportion the DC/WAN energy consumption. This requires an estimate of the data traffic in the DC/WAN by device type (in GB or EB). The upstream energy use to attributed to devices by the following calculation:

$$Upstream\ Energy_{device}(y) = Data_{device}\ (y) \times Stock_{device}\ (y)\ \times EI(y)$$

Where

$Data_{device}$ = average annual data traffic for each device in year *y*

$Stock_{device}$ = total stock for the device type in year *y*

EI = Energy intensity (kWh/GB) of the DC/WAN in year *y*

The proportion of network data traffic generated/consumed by device type is calculated as follows:

$$Data_{device}(y) = IP\ Data_{category}\ (y)\ \times IP\ Share_{device}(y)$$

Where

$IP\ Data_{category}\ (y)$ = the projected data consumption for the IP data category in year *y*

$IP\ Share_{device}\ (y)$ = the share of IP category data for each device type of the category in year *y*. This is calculated from the estimated monthly data consumption per device type and the share of stock of the devices in the IP data category for year *y*

These estimates are currently limited to attributing the upstream energy use for all DC/WAN energy consumption to the device type, regardless of the network that being used to communicate or IP data category. Segmentation can be included in the TEM to account for different devices mainly using a particular network (i.e., mobile devices using only the mobile radio WAN) or the type of data being consumed from a particular platform (i.e., video streaming devices using content distribution data centres). The energy intensity for each of these attributes is different and this aspect was not included in the TEM due to the modelling priorities for the study.

3.2 Definition of classifications and categories

The network-connected energy use of devices is further characterised by the following:

- Region (global plus 8 regions)
- Sector/Segment (sectors include residential, business and public)
- Device classification. A taxonomy of four classifications to enable the reporting of results, such as type (Edge -device), category (functions such as security, automation), group (similar devices) and device.
- Type of upstream data use, aligned to the global IP traffic by device type defined by CISCO (CISCO, 2018). This classification is used to attribute the WAN and Data Centre energy use attributed to each connected device.

3.2.1 Regional classifications

The model is structured to enable regional estimates to be developed, however only global network-connected energy use is currently calculated. Because data is not available for all countries in some regions, the model is currently populated at the global level. Where regional data is available, such as

internet connections by region or number of households, these inputs are used to develop certain device installations. For instance, the estimated LAN equipment installations are developed from data on internet connections by region and the number of network-connected appliances are developed from household appliance ownership by region.

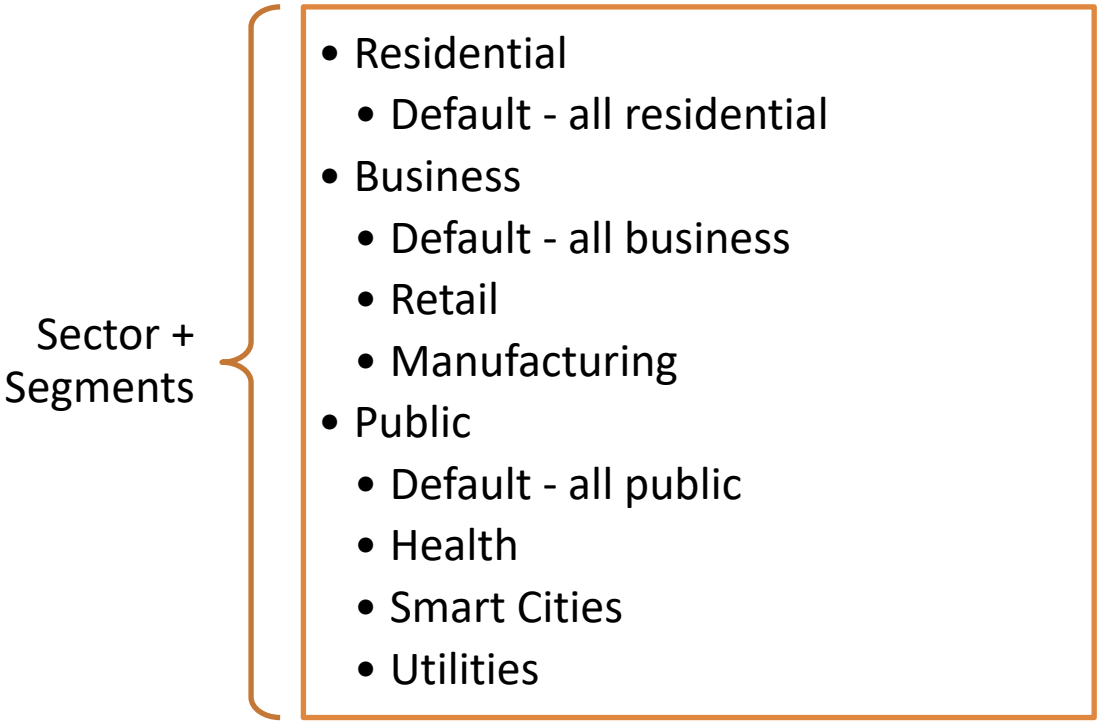
The regional classifications are largely based on regional differences in appliance and equipment installed. There are eight regions defined in the model, as follows:

- North America
- Europe (including Russia)
- Asia-High Income (excluding China, but including higher income Asia pacific countries)
- China
- India
- Asia (remaining Asian countries with lower Gross National Product/person)
- South America
- Africa

3.2.2 Sectors and segments

The model is able to calculate the energy use of connected devices by sector and segment of the sector (if applicable). The model uses a default segment which assigns all devices to the sector classification, unless there is specific data to allow for the devices to be classed within a segment of the sector. The sectors and segments identified are shown in Figure 2.

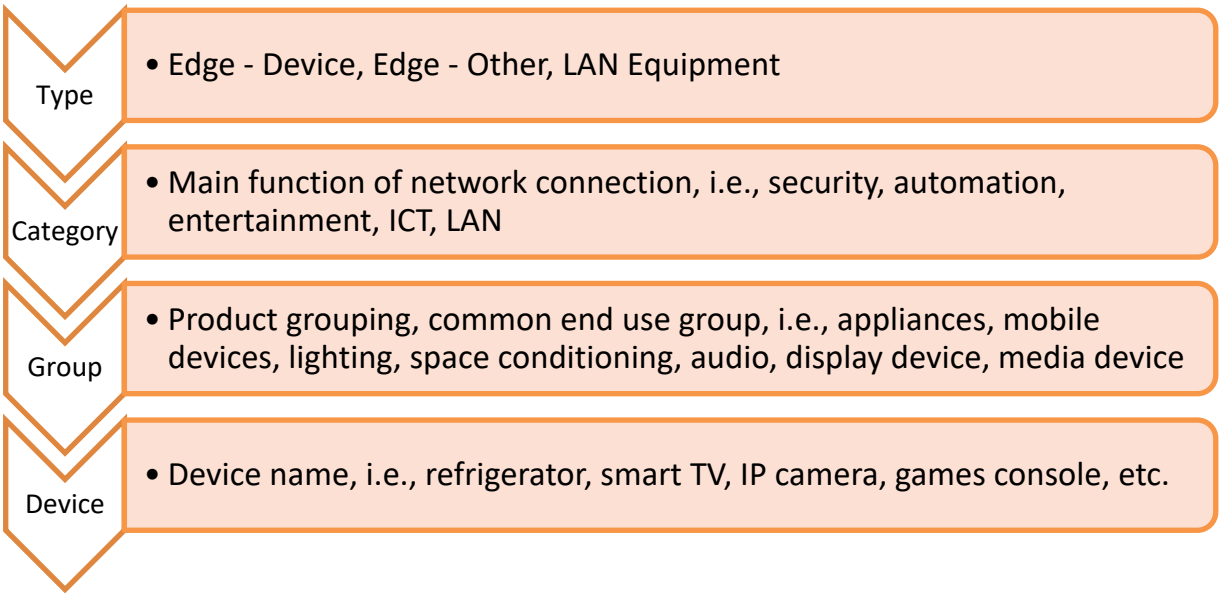
Figure 2: Sectors and segments



3.2.3 Device classifications

The main types of edge equipment are classified in the same way as previous studies (IEA, 2017), by edge – device, edge – other and LAN equipment. Further classifications are then provided to be able to more easily aggregate major functions and disaggregate energy use and inputs to particularly device types. This device classification hierarchy is shown in Figure 3.

Figure 3: Device classification scheme

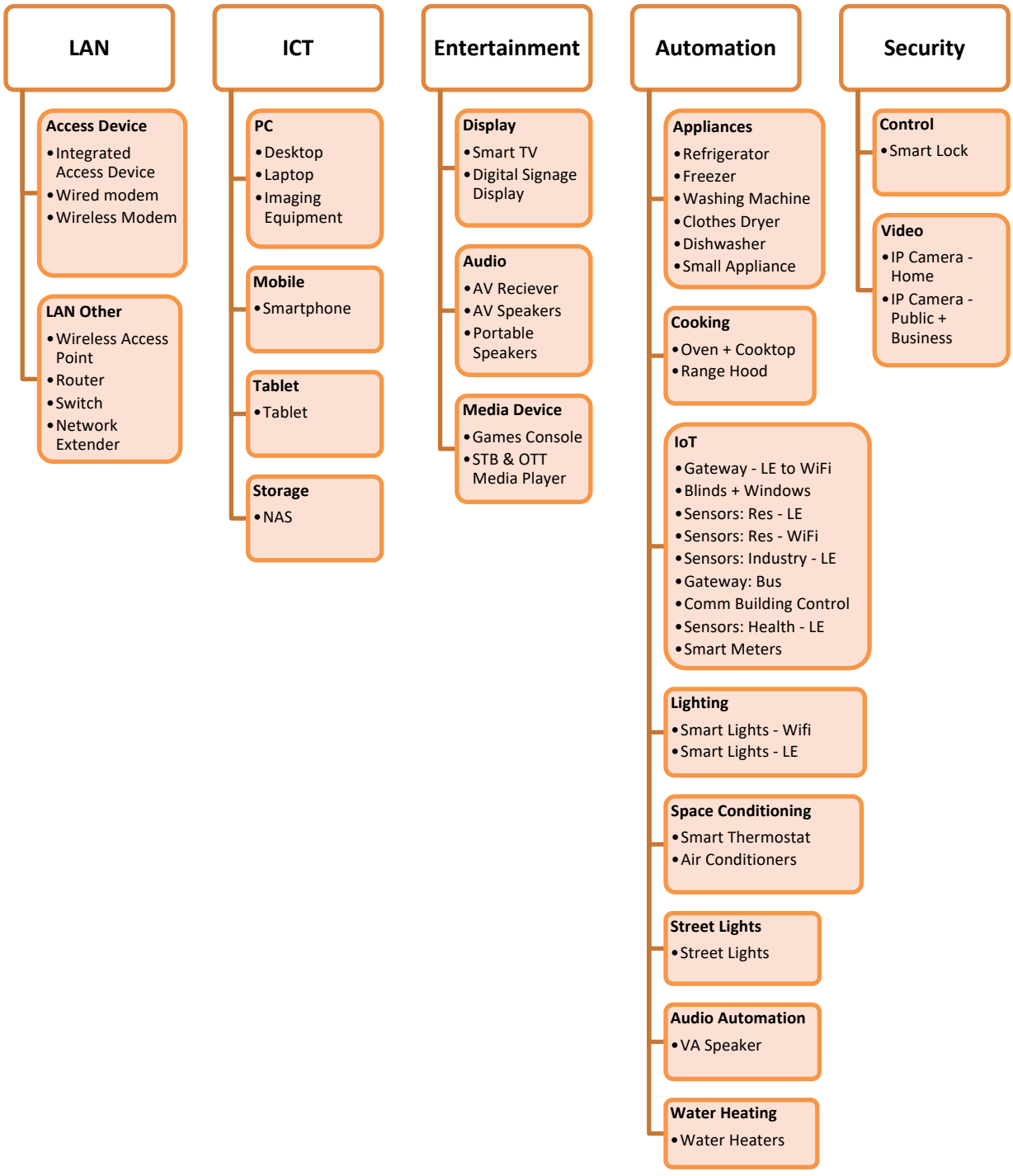


All the devices included in the TEM are shown in Figure 4, classified by category (in the top row) and group (in each box). The five categories are:

- LAN – which includes all wired and wireless LAN equipment
- ICT – which includes PCs and peripherals, laptops, mobile phones, tablets and storage devices on the edge of the network
- Entertainment – which includes displays, audio devices and media devices
- Automation – which is a large category of connected appliances, devices, sensors and controls
- Security – which includes video cameras and physical access controls such as smart locks

The power consumption and usage characteristics of these devices are described in Appendix A: TEM connected devices – calculations and assumptions, and can be different for each of the sectors considered in the TEM.

Figure 4: Device classifications by group and category



As some of the abbreviations may not be easy to interpret, specific groups are described in detail. For the Automation category, IoT group, the connected devices, by the network connection if applicable, are as follows:

- Smart Meters. All utility connected meters
- Sensors: Res – Wi-Fi. Residential sector Wi-Fi connected sensors
- Sensors: Res – LE. Residential sector low energy network (Bluetooth, ZigBee, NB-IoT, etc) connected sensors
- Sensors: Health – LE. Health sector low energy network (Bluetooth, ZigBee NB-IoT, etc) connected sensors
- Sensors: Industry – LE. Industrial sector low energy network (Bluetooth, ZigBee) connected sensors
- Gateway: Bus. Commercial and industrial sector network gateways for sensors and controls
- Gateway - LE to Wi-Fi. Residential sector network gateway to Wi-Fi and wired networks for sensors and controls using low energy network connections
- Comm Building Control. Commercial sector sensors and controls, using low energy and Wi-Fi network connections
- Blinds + Windows. Residential sector network-connected controls for blinds and windows

3.2.4 Upstream data by device classification

The TEM uses the IP global traffic by device from the Cisco Visual Networking Index (VNI)(CISCO, 2018) to attribute upstream data traffic to the network-connected devices. Therefore, all the devices are classified by the categorisation reported by CISCO, as follows:

- PC
- TV
- SmartPhone
- Tablets
- M2M
- Non-Smart Phone
- Other

The global IP traffic by device category is shown in Figure 7.

3.3 Features and functionality

3.3.1 Introduction

The TEM is a highly flexible stock and energy model of the energy use of network-connected devices. The principle aim is to enable the calculation of network-connected energy use of connected devices and their upstream energy impacts. This supports policy analysis by identifying the major areas of network associated energy use and can be used to drill down to the specific products.

The key features are:

- Capacity for 200 devices, with 77 currently described
- Power use characteristics of devices by condition/state (network active and network standby) are entered for devices installed in a particular year and trends applied to enable this to change over time

- Hours of power use by condition/state are entered by device
- A flexible life function is used to described the remaining devices in the stock
- Additional descriptors are provided to identify the power source (mains power, rechargeable battery, etc.) and the network connections (wired, Wi-Fi, Zigbee, LPWAN (IoT), Mobile, etc.)

A key aspect for modelling the stock is estimating and entering the annual sales/installation of devices. The model accepts multiple data sources of installation data, depending on the information sources. Normally, a bottom up model is limited to entering the sales of devices by year, however the TEM can calculate the sales of devices based on the estimated stock by year (or ownership/penetration combined with a parent value such as households or businesses). The TEM accepts all these types of inputs:

- Sales by region or global values and the share of sales by region
- Stock by region or global values and the share by region
- Ownership of products by region or global values and the share by region

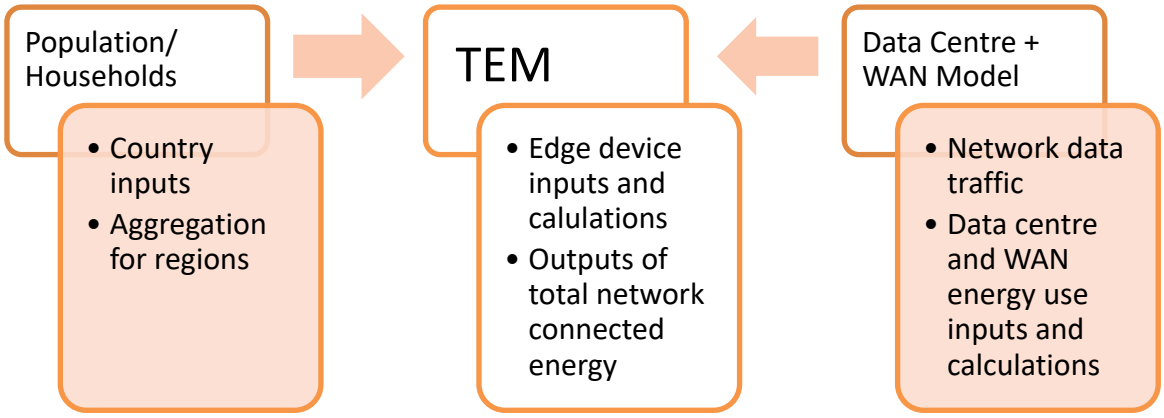
In addition to these device installation inputs, the TEM also has the ability to calculate the number of connected devices based on the share of all the products (connected or not connected) that are sold with a network connection, for instance, a gradual increase in sales share of refrigerators that are sold with network connections (by region or global).

The model has a number of general inputs by region which enable more accurate estimates to be made of certain product types. The common inputs include the number of households, population, fixed broadband connections and gross national income by region.

3.3.2 Structure

The model was specified to be built in Excel, which limits some of the capacity to create a rational normalised database of inputs. In general, however, the model uses input sheets and calculation sheets at the regional level (however only global values are populated in this version). A key feature of the model is the outputs are provided in a "flat file" database structure to enable pivot tables/charts to be developed for almost any combination of classification variables (sector, segment, product, etc.) and fields (stock, sales, energy use network active, energy use network standby, upstream energy use, data consumption). The structure of the model is shown in Figure 5.

Figure 5: TEM structure



The outputs enable the display of key outputs by region (in future versions), sector/segment, categorisations and year, including:

- Network-connected energy use by network state and upstream energy consumption
- Stock and sales of products

3.4 Sources and assumptions

3.4.1 Edge device and network equipment component

The TEM uses a large number of data sources and assumptions. These assumptions and related projections of equipment numbers and characteristics become inherently less robust the further the time period of the projection. The future of network-connected technologies and systems are rapidly changing, and research organisations are revising their projections of the total number of connected devices. For instance, early in this decade the total number of connected devices was forecast to be 50 billion in 2020, however this was revised (in 2016) to be between 20 - 30 billion (IEEE Spectrum, 2016). The current forecasts are 38.5 billion in 2020 and 50 billion by 2022 (Juniper Research, 2018), 21 billion in 2020 and 25 billion by 2022 (IoT Analytics, 2018). The model has used multiple sources of forecasts of global sales of devices by type and calculated similar stock numbers to the IoT Analytics forecast.

The model uses key assumptions and sources of data relating to the number of broadband connections, households and population by country to obtain estimates of the stock of LAN equipment and certain common appliances. The main sources and assumptions are outlined below:

- UN data by region
    - Population and household size (historical + forecast)(United Nations, 2017b, 2017a)
    - ITU data on fixed broadband connections (historical)(ITU, 2018)

- Assumptions/approach
    - Forecast broadband connections by region are estimated based on historical trends determined from the data collected (ITU, 2018)
    - Forecast households per country are estimated from the UN population forecasts and trends in historical propensity (persons/household) (United Nations, 2017b, 2017a)
    - Finally, the total number of connections and certain common types of equipment are separated in the sectors (residential, businesses public) using estimated values or sourced data (CISCO, 2018)[2].

For the connected edge devices, the main drivers of the energy consumption projections are the number of devices installed and the power use of their network port. The bottom-up model uses sales (or installations) of devices as the primary input, however as noted earlier, the stock of products can also be used to estimate the sales in a particular year. A special function was developed that enables the calculation of sales of products by year, based on the stock of the products and their average life and similar the function used in other bottom-up energy models (McNeil *et al.*, 2012). These two broad approaches allow the calculations of sales by year from a range of data sources. If the product sales are not available, the ownership and stock of products was researched to determine sales inputs, using the logic explained before.

The annual sales for many products are directly input into the model from industry research organisations, such as Juniper Research[3], IDC[4], Gartner[5], IHS Markit[6] and Global Market Insights[7]. In total, there are over 200 references captured in a library that are available for EDNA to use as a resource. These references generally report global sales or shipments of products[8], over the time period from 2010 to 2017, and forecast to 2023. Therefore, projected growth rates of sales post 2023 were assumed to be similar to the previous trends and adjusted to ensure that realistic stock values are produced. The household sector sales or stock of connected devices, such as smart home devices, and common devices such as smart phones, PCs, tablets, were reported by multiple research organisations. However, business, public sector and industrial connected devices sales or stock (such as sensors, lights and controls.) were often not disaggregated, and usually only available from a limited number of sources. Therefore, these products are shown as classified as one aggregated device type in the model (i.e., commercial building controls) and hence are less robust. A detailed list of approximately 200 sources used to populate the TEM is found in Appendix C: Detailed sources of information for the TEM.

Power use by network condition and hours of operation by condition was obtained or estimated from several sources, these include:

[2] By 2021 the consumer share of the total devices, including both fixed and mobile devices, will be 71 percent, with business claiming the remaining 29 percent, according to CISCO
[3] https://www.juniperresearch.com/
[4] https://www.idc.com/
[5] http://www.gartner.com/
[6] https://ihsmarkit.com/
[7] https://www.gminsights.com/
[8] The reports identified are available for purchase in the range of $2,000 to $10,000 each, and would be valuable sources of regional data if EDNA or other policy development organisations wished to obtain them.

- EDNA basket of products and IT measurements conducted by member countries (confidential)
- Measurements of smart home devices (2016 -2018), provided by Choice[9] (Australia), a consumer advocacy, testing and research organisation
- USA Consumer Technology Association research (Fraunhofer, 2017)
- 4E reports(Harrington and Nordman, 2014; EDNA, 2016; EDNA 4E TCP, 2016)
- EPA and EU ENERGY STAR® reporting

These sources of information often reported on power or energy use for devices over historical periods for network standby and network active conditions. The trends in power use over time were estimated from these historical measurements or reported values, and extrapolated. In some cases, the trends showed lower power consumption over time, but in other cases the power consumption increased, such as with integrated access devices (Fraunhofer, 2017). Where average power consumption for devices was not available from these sources, it was estimated, based on the network connection type (i.e., Wi-Fi, Ethernet, BLE, Zigbee, NB-IoT) and the power source used (i.e., rechargeable battery, non-rechargeable battery or mains power). The evidence from other EDNA reports shows that certain device network interfaces can provide a reasonable basis for estimating the network standby power consumption (Xergy Consulting, 2018).

Where available, the sales-weighted average power use values were used as this is the necessary input for the TEM. If this value was not provided, the average power use of the devices measured or reported was determined and provides a reasonable substitute for sales-weighted average values.

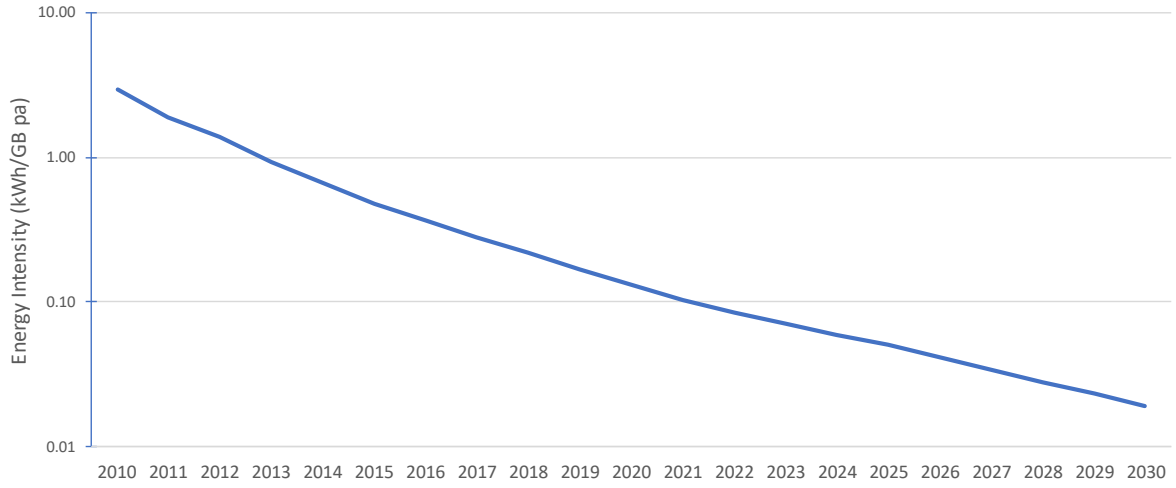
Detailed assumptions regarding the sales estimation approach, power consumption by network state, hours of use, service life of products and other characteristics are shown in Appendix A: TEM connected devices – calculations and assumptions.

3.4.2 Upstream component

Upstream energy use by connected devices is derived from the relationship between IP traffic by device type and the energy intensity of IP data traffic of the DC and WAN. The DC and WAN energy intensity is shown in Figure 6. The figure shows that energy consumption per GB is 3 kWh/GB in 2010, 0.22 kWh/GB in 2018 and 0.07 kWh/GB in 2025, a 77% reduction from 2018. Energy intensity of the upstream network (DC/WAN) is decreasing rapidly due to changes to the architecture and efficiency of the DC and WAN equipment as new technologies are introduced and the total traffic increases. The majority of the increase in data traffic is due to the increase in video content delivery, with IP video traffic projected to account for 82 percent of traffic by 2021 (CISCO, 2018).

[9] https://www.choice.com.au/

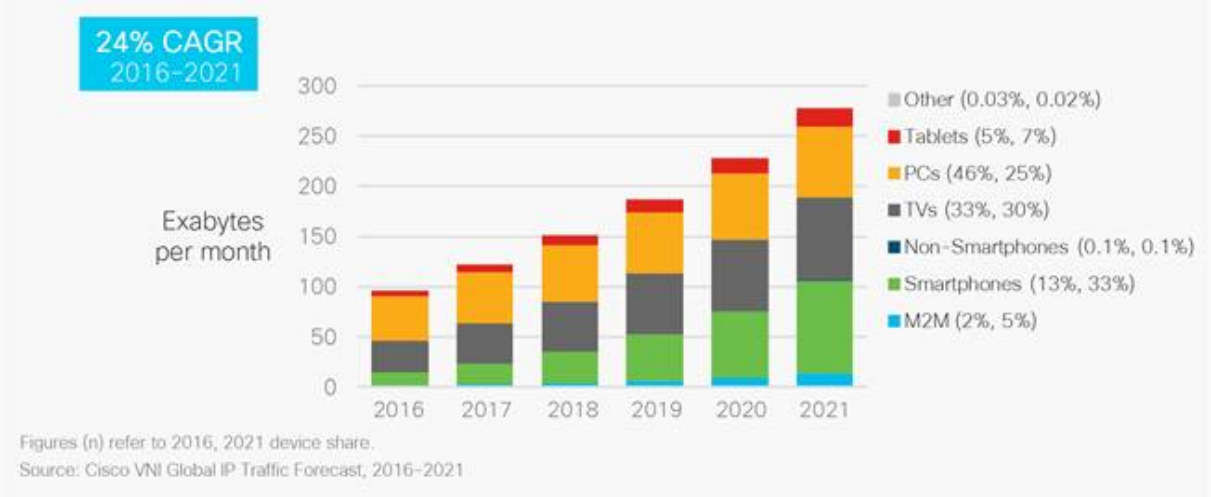
Figure 6: Energy intensity of DC and WAN by year 2010 - 2030



Note: Logarithmic scale of energy intensity, Source: (EDNA, 2019)

At the same time, data traffic is forecast to increase 2.5 times over the period 2016 to 2021 (CISCO, 2018), as shown in Figure 7.

Figure 7: Projected Global IP traffic by devices

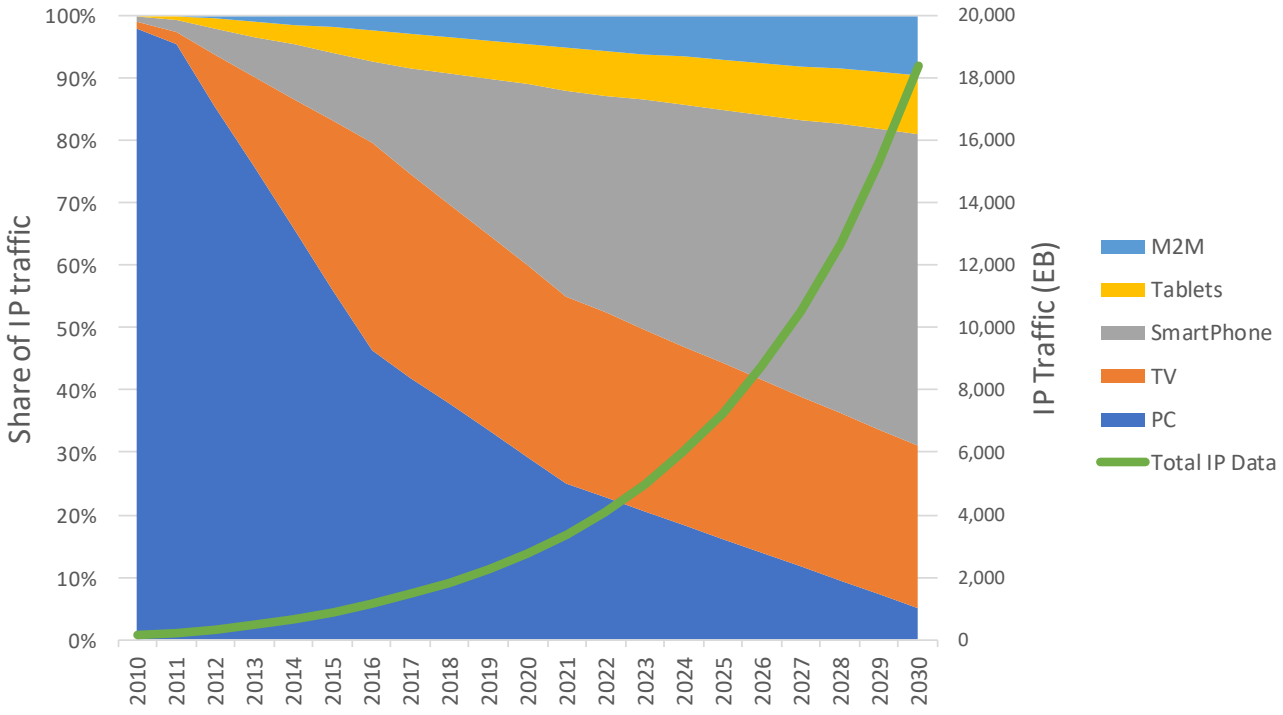


Source: (CISCO, 2018)

The data traffic allocated to each of the IP traffic categories in the TEM is further separated by device on the basis of reasonable estimates of monthly traffic within each IP category. This allows the upstream energy use to be attributed to each connected device according to the proportion of data traffic.

Figure 8 shows the share of data traffic by IP category on the left hand scale and the total estimated IP traffic across the WAN in Exabytes (EB). The IP share and traffic are from found in publications and research by CISCO, and are only available to 2021 (CISCO, 2010, 2018). The TEM has extrapolated these trends for the period 2022 to 2030.

Figure 8: Share of IP traffic by IP category and total IP traffic (EB) 2010 – 2030



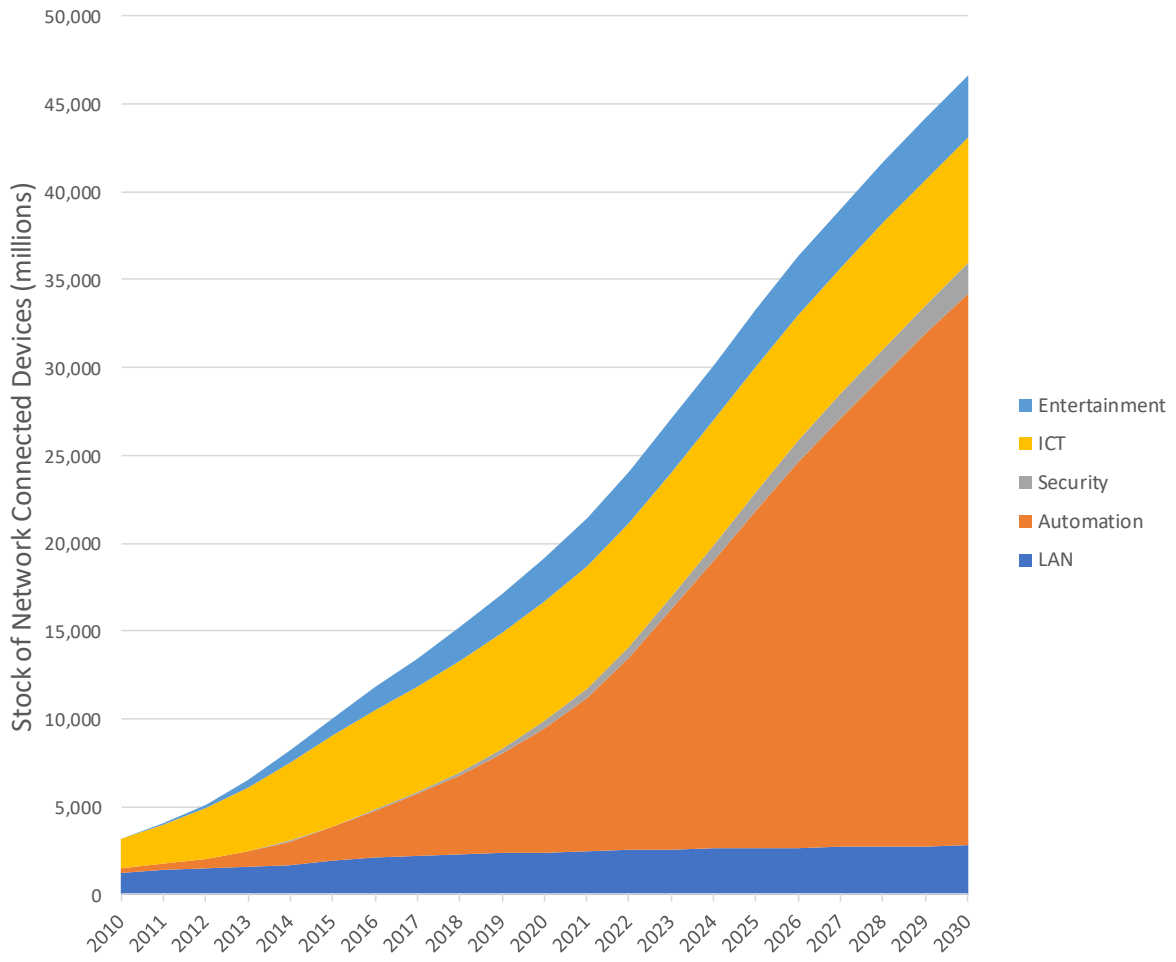
Further details of the devices considered, classifications, sales input approach, active/standby network power and trends, hours of use and the scope of the network-connected energy is shown in Appendix A: TEM connected devices – calculations and assumptions.

4 Projected stock and sales of network-connected devices

4.1 Overview of stock and sales of network-connected devices

The total number of installed network-connected devices including LAN equipment, as projected from the TEM, is shown in Figure 9. Throughout this report, projections start from 2018.

Figure 9: Stock of network-connected devices by category 2010 – 2030

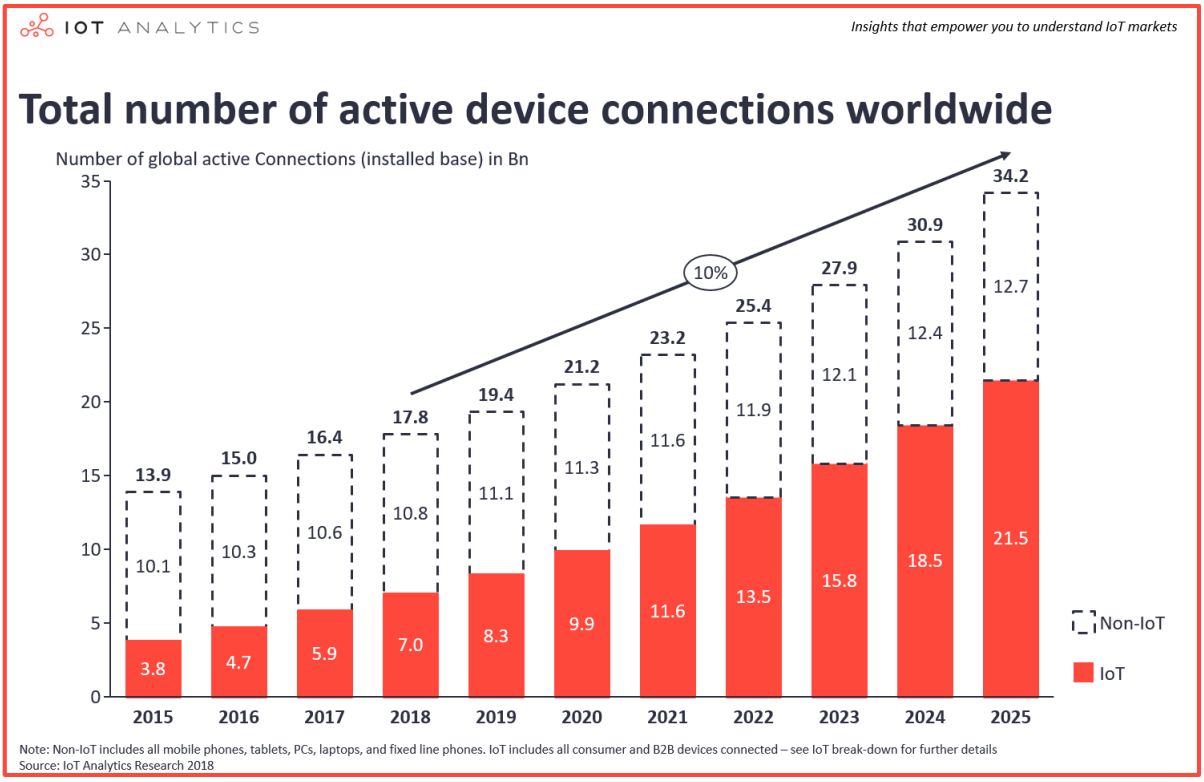


The growth of network-connected devices is rapidly increasing, from an estimated 15 billion in 2018 to 46 billion in 2030. This represents a 300% increase from 2018 to 2030, or an average compound annual growth rate (CAGR) of 9.8%. The majority of this growth is related to automation network-connected devices, which includes sensors, controls (often termed IoT) and connected appliances.

The TEM has estimated the global stock of 77 device types, utilising information from over 200 sources of information (see Appendix C: Detailed sources of information for the TEM). There are a number of industry research organisations that estimate and forecast the number of network-connected devices installed, however there are differences in the scope of products included. As a comparison to the TEM projections, the industry research group IoT Analytics (IoT Analytics, 2018) has produced an

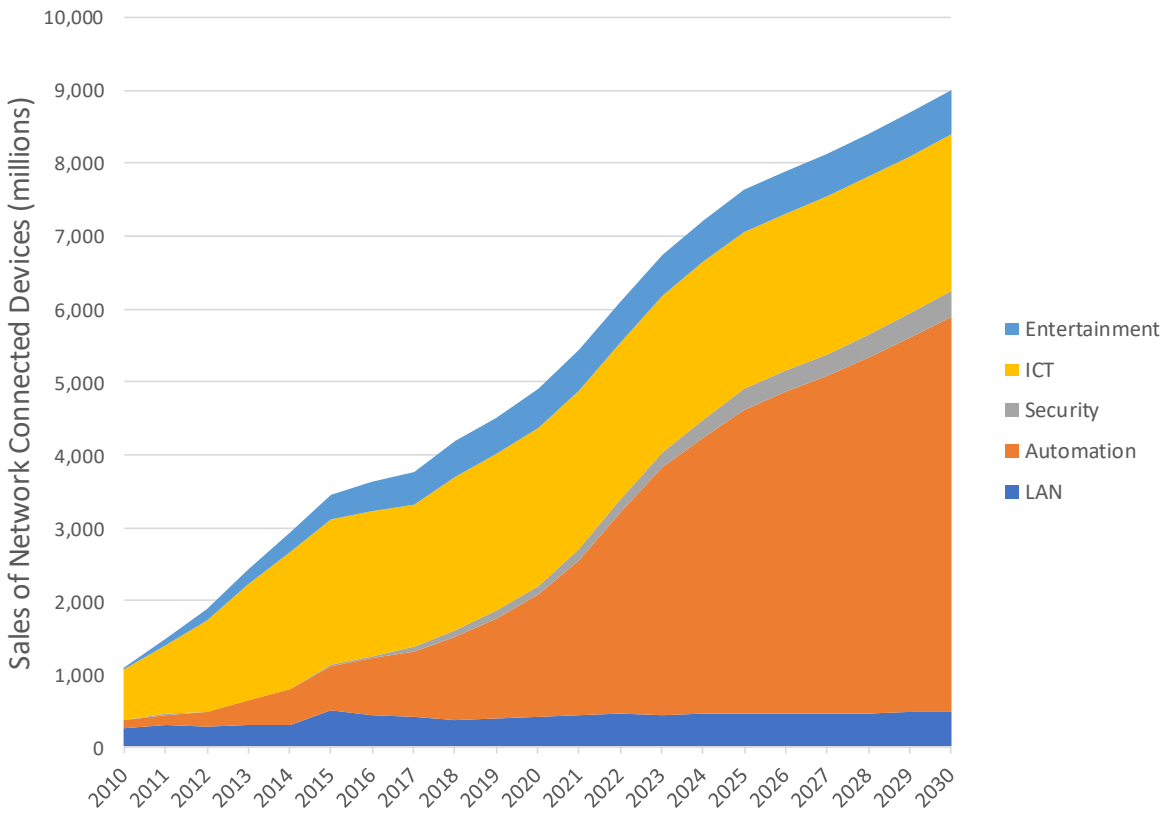
estimate and forecast using a comparable scope of devices, as shown in Figure 10. The estimated current and forecast of active device connections to 2025 by IoT Analytics is very close to the TEM projected number of connected devices.

Figure 10: Industry projections of connected devices 2015 – 2025



The network-connected device sales data used in the TEM is shown in Figure 11. As described in Chapter 3. Methodology, the TEM uses the sales data as an input to the calculation of the stock. Sales data for each of the different product types is based on multiple sources of information (see Appendix C: Detailed sources of information for the TEM) and are extrapolated to 2030 if the source does not forecast to this date.

Figure 11: Sales of network-connected devices by category 2010 – 2030

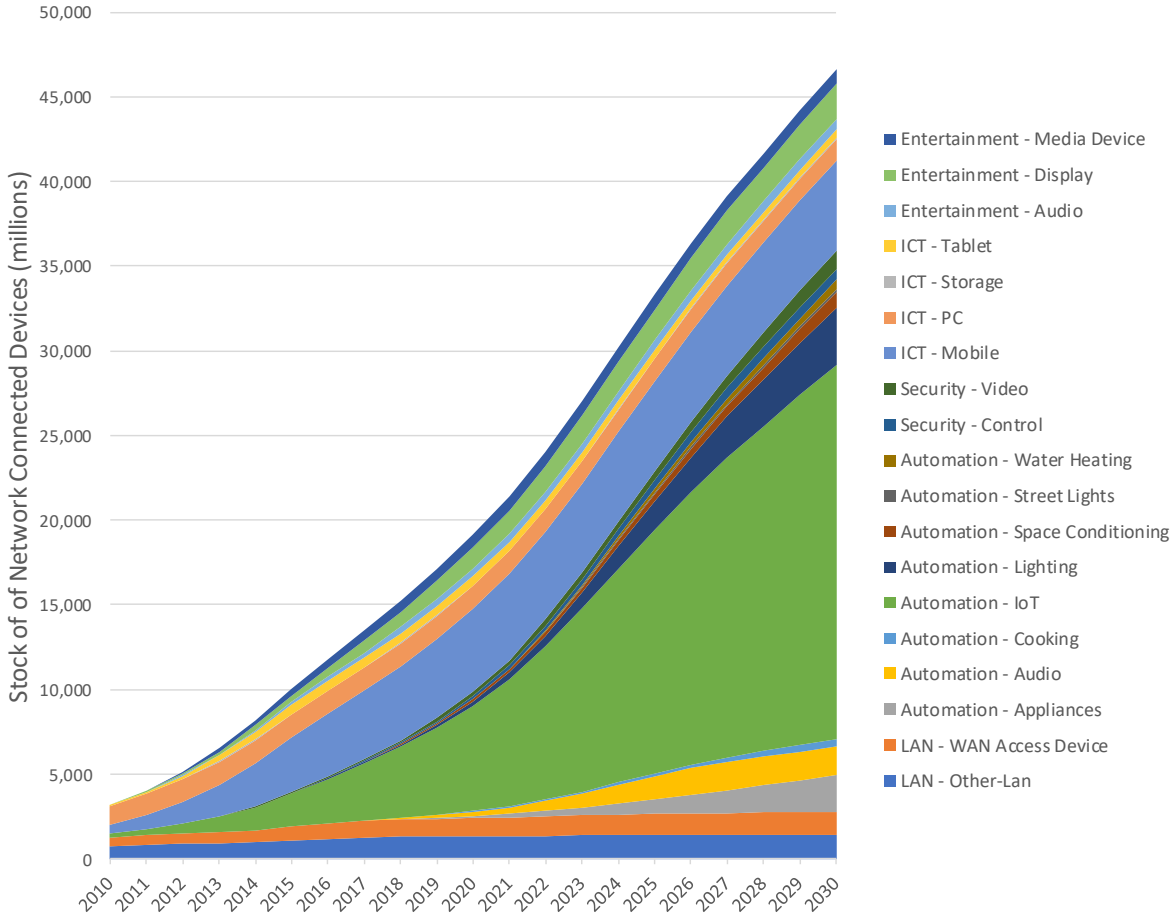


The sales of networked connected devices in the automation category exhibits the largest projected growth over the period 2018 to 2030.

4.2 Stock of network-connected devices by category and group

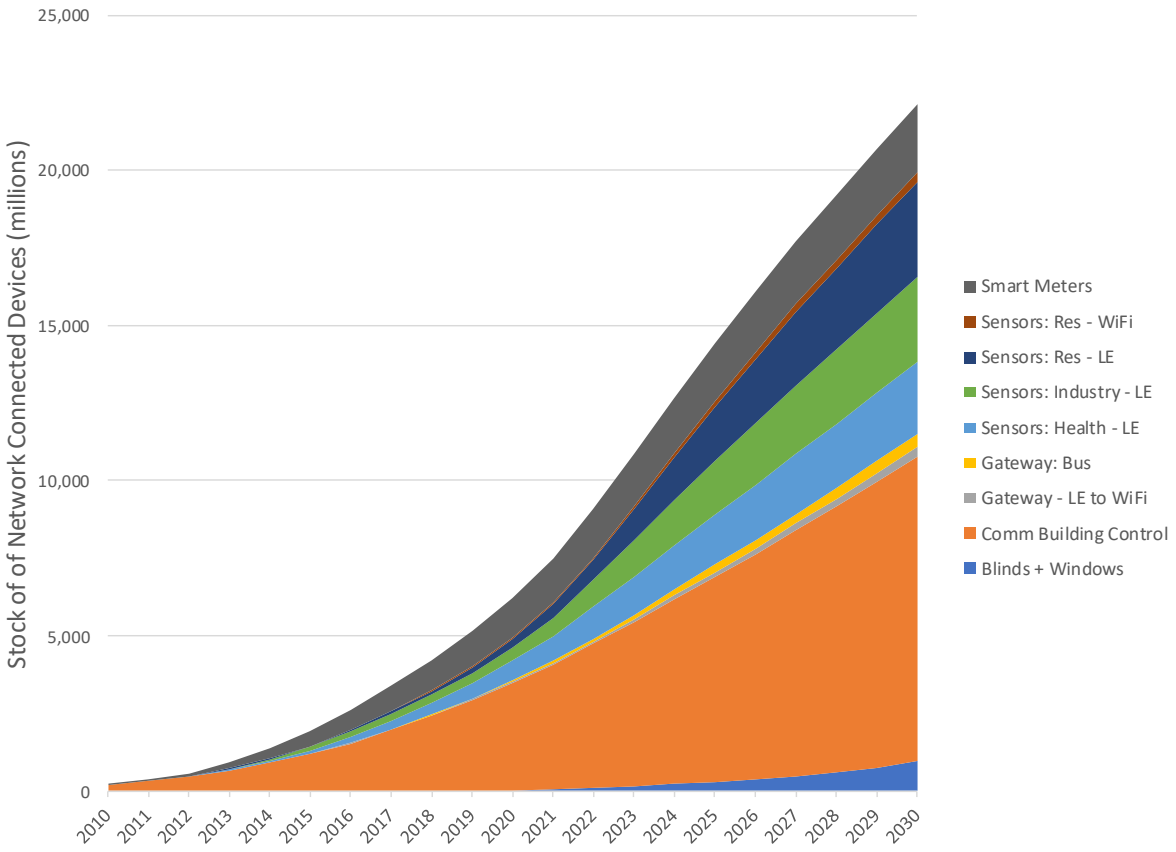
The total stock of network-connected devices by year, category and group is shown in Figure 12.

Figure 12: Stock of network-connected devices by category and group 2010 – 2030



The largest increase in stock is within the Automation - IoT group, which is specifically disaggregated in Figure 13.

Figure 13: Stock of network-connected Automation - IoT devices 2010 – 2030



Note: LE means low energy mesh or low energy wide area networks

The largest proportion of stock of IoT automation devices are commercial building control devices. Only the aggregated sales of this group is available for this study. To disaggregate these devices into sensors/actuators and other controls is not possible at this stage due to a lack of available information sources.

5 Total network-connected energy consumption

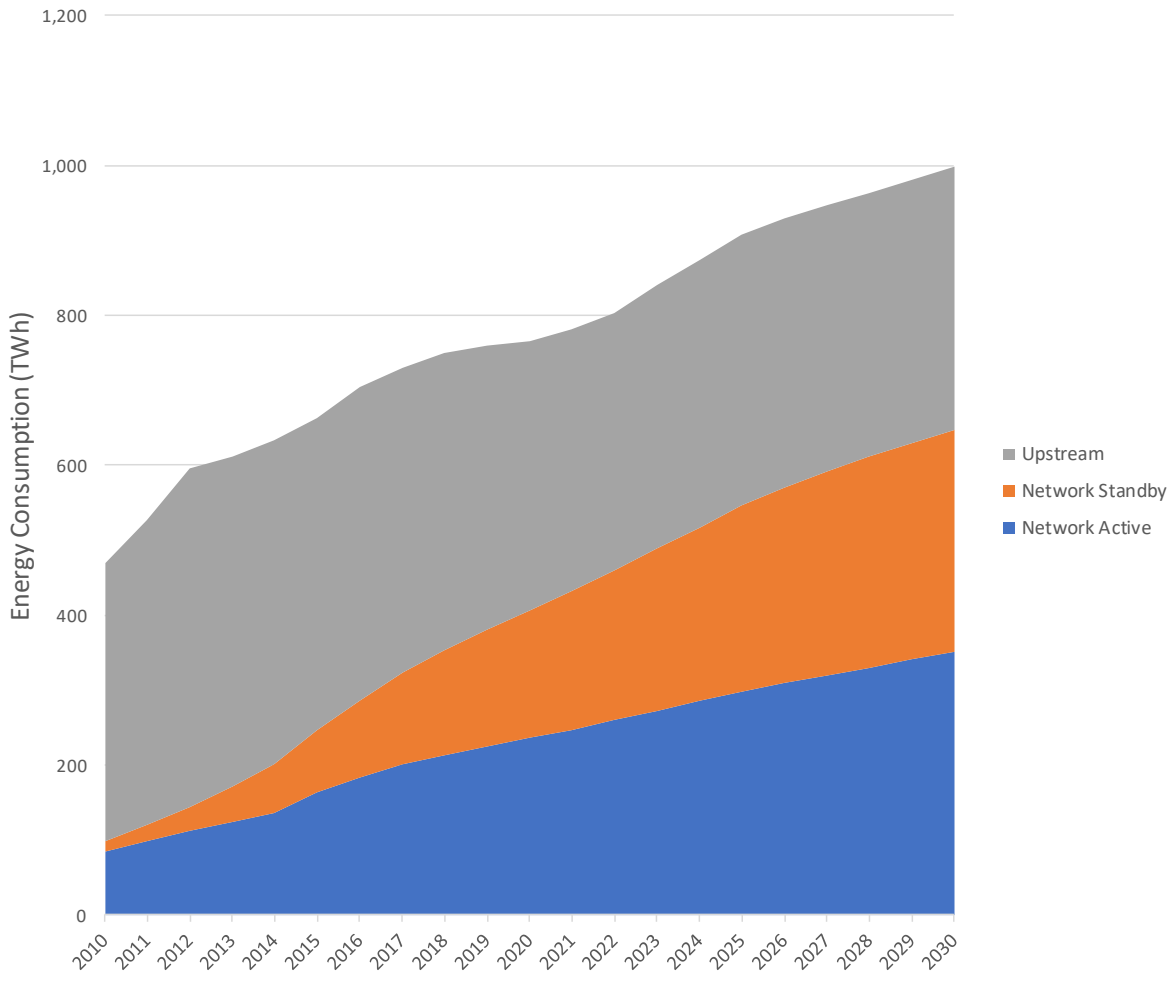
5.1 Overview

5.1.1 Total network-connected energy consumption

The total energy consumption due to devices becoming connected to the network is shown in Figure 14 and includes three main components, as follows:

- Upstream energy use of the communications and data networks and the data centres – which is increasing till 2012 and slowly decreasing
- Network standby energy use of the edge equipment, which is rapidly increasing over the period as more devices are connected
- Network active energy use of the edge equipment and LAN equipment, which is also increasing over the period

Figure 14: Network-connected energy consumption by component 2010 -2030



With global electricity demand rising from 20,500 TWh in 2014 to 28,600 TWh in 2030 (IEA, 2016), the share of total network-connected energy consumption of total electricity demand is 3.1% in 2014 and projected to be 3.5% in 2030.

Network standby energy use of connected devices is projected to grow from 64 TWh in 2014 (0.3% share of electricity demand) to 300 TWh in 2030 or 1% of total electricity demand. The network-connected energy consumption by network state and category is shown in Appendix B: Model Output tables.

A further breakdown of the network-connected energy use of devices by IP type is shown in Figure 15. The solid area is the network energy use of connected devices and the stripped area is the upstream energy use associated with the device.

Figure 15: Network-connected energy consumption by IP device type 2010 – 2030

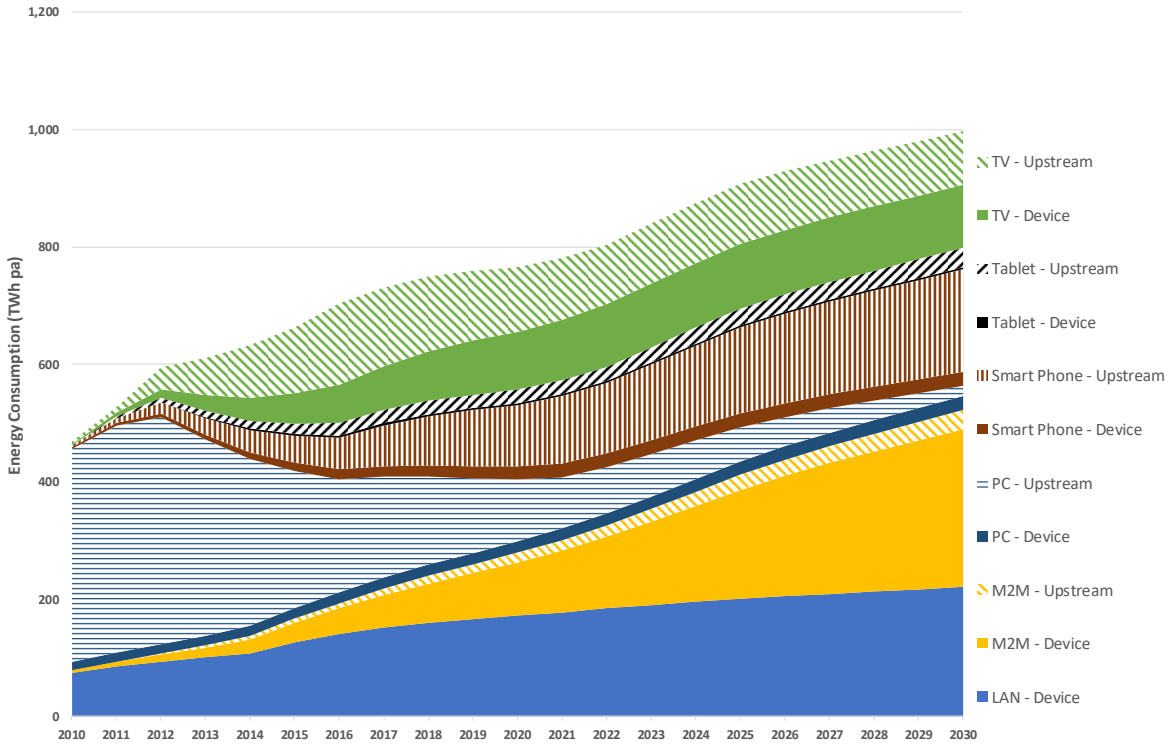


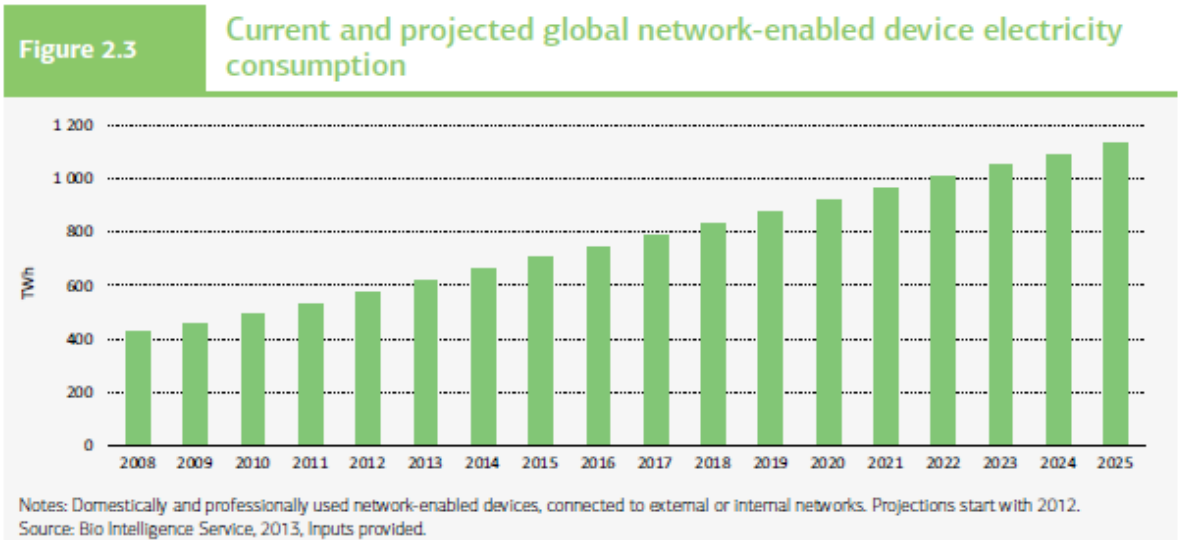
Figure 15 shows the size of network-connected energy consumption for devices and the magnitude of consumption attributed to these devices in the upstream network and data centres. The LAN equipment does not incur any upstream energy use the modelling, as it is assumed that no data is generated solely by this equipment, however energy use increases significantly from 75 TWh in 2010 to 220 TWh in 2030. The largest increase in device energy use is due to M2M (machine to machine) devices, however their upstream energy use is low because they have lower data transfers compared to other devices. Interestingly, this situation is reversed with smart phone and tablet proportion of device energy use compared to their upstream energy use. These devices have lower network-connected device energy use relative to their upstream energy use, due to their more significant consumption of data intensive applications (e.g., video). The TV category (which is a category of related IP devices such as smart TVs, STBs and over the top (OTT) streaming devices) exhibit the second

largest increase in network-connected energy use at the device level. Over the modelling timeframe, the upstream energy use of PCs decreases while smart phone upstream energy use increases.

5.1.2 Comparison to other studies

Differences in scope of devices and energy use states make it difficult to directly compare the TEM outputs with similar studies. In the TEM, the projected energy use does not include the energy use of the PCs or other equipment in "on mode", only the networked connected energy use is included, as defined in the Scope of Study. The total energy use for all connected devices and upstream energy use are reported in several studies, but as noted in the recent IEA *Digitisation and Energy* report (IEA, 2017), differences in time, scope/boundaries, assumptions and data sources make any direct comparisons across studies difficult. The IEA publication *More Data Less Energy* (IEA, 2014) is closer in scope than other studies as it estimates the energy use for network-enabled device energy consumption, however it includes all modes of energy consumption of connected devices, including PC and TV on-mode energy consumption. This IEA study shows energy use increasing from 500 TWh in 2010 to 1,150 TWh by 2025, as shown in Figure 16. The TEM estimates network-connected energy consumption is 100 TWh in 2010 and 550 TWh in 2025. Considering the TEM focuses only on the network-connected energy use and has used more recent data sources, the differences are explainable. For instance, the active/on-mode power consumption of PCs is 25 times higher than the network-connected power consumption mode attributed to PCs, and the on-mode power consumption of connected TVs is 100's of times higher than the network standby power consumption. Although the TEM does not quantify the on-mode energy consumption, initial investigations of the impact of adding only PC on-mode energy consumption to the TEM model show that this increases energy consumption to 250 GWh in 2010. This indicates that the TEM outputs are likely to be comparable to the IEA publication *More Data Less Energy* (IEA, 2014) when accounting for differences in scope.

Figure 16: IEA projected global network enabled device electricity consumption



Source: (IEA, 2014)

Another study, prepared for EDNA, estimates the network standby energy consumption of IoT devices (EDNA 4E TCP, 2016), which is projected to be 45 TWh in 2025. The TEM estimates the network

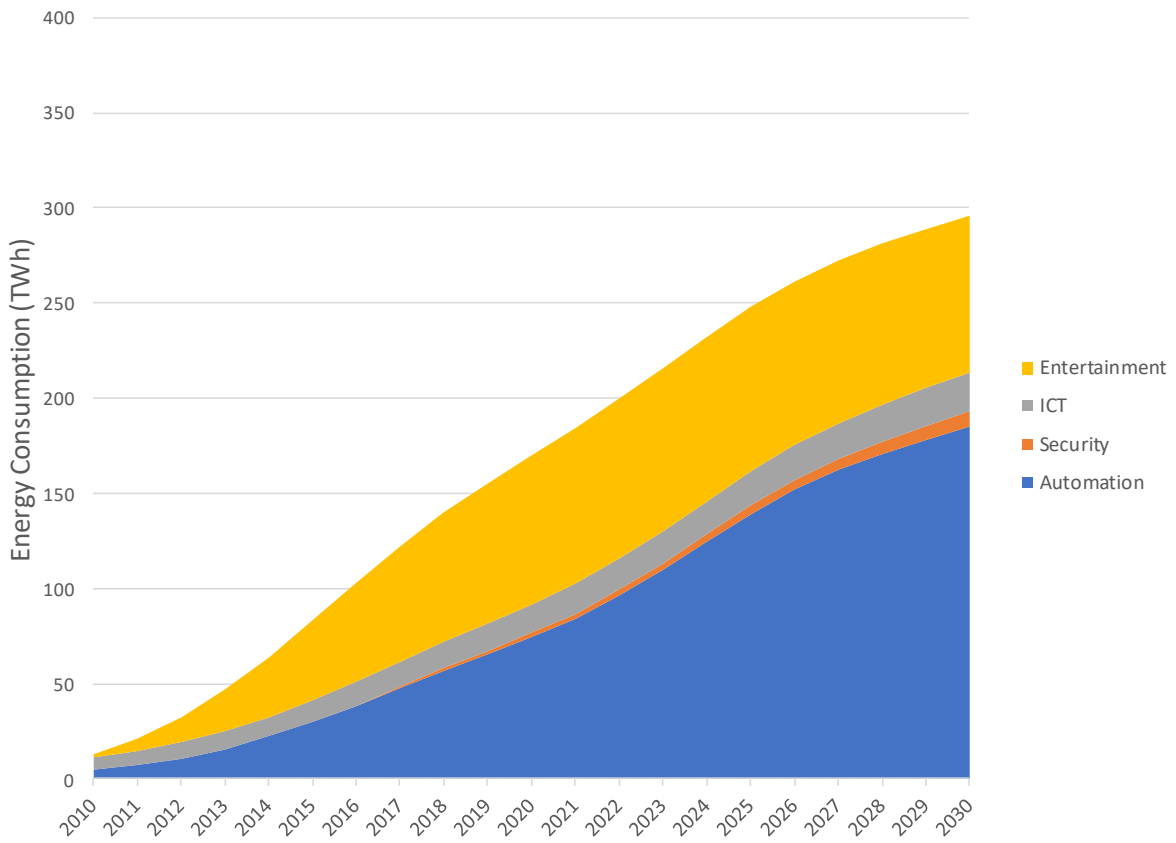
standby energy consumption for this category to be significantly higher, mainly due to the use of more recent data on devices and larger projected stock, compared to the 2016 EDNA study.

5.2 Network-connected energy use of devices by network state

The focus of the TEM is to provide information that will be of use to energy efficiency policy development of network-connected devices. Network standby energy use is the target of significant policy actions internationally, and is projected to increase over the modelled period.

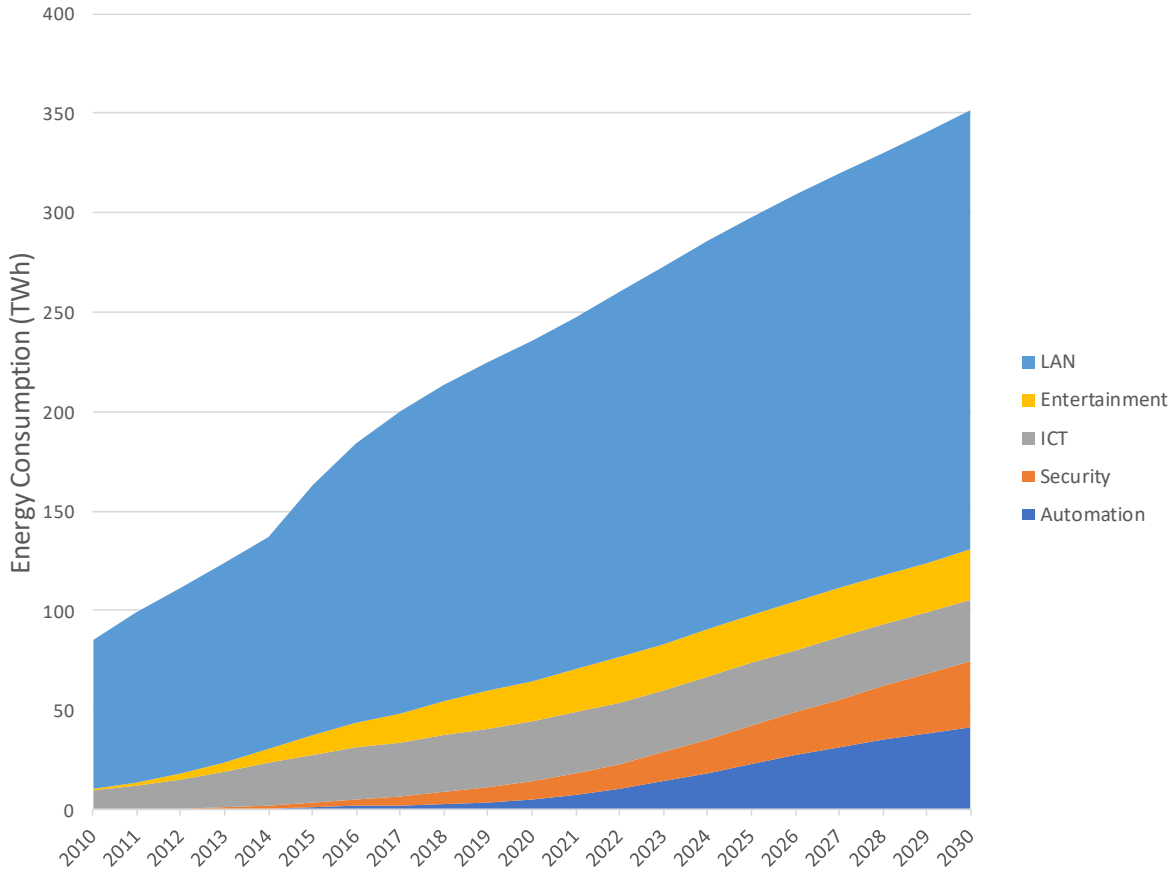
Figure 17 shows the network standby energy consumption of connected devices and Figure 18 shows the network active energy consumption.

Figure 17: Network standby energy consumption of devices by category 2010 – 2030



The network standby energy consumption of all devices is projected to double from 2018 to 2030. This is largely a result of the increasing installations of entertainment and automation devices, and the type of network connections that are used. The contributions of each group of devices for the automation category is shown in section 5.3.1, and for the category, in section 5.3.2.

Figure 18: Network active energy consumption of devices by category 2010 – 2030



The majority of network active state energy use is attributed to LAN equipment. This network active state energy use is increasing due to the increasing number of internet connections and also an increasing power consumption per device, due to more functional devices (such as integrated access devices, which combine WAN connections/modems with routers and access points). The global number of fixed broadband connections has grown to 998 million in 2017 according to the International Telecommunications Union (ITU, 2018) and is set to surpass 1 billion by 2018. Growth in fixed broadband connections was over 2% (per quarter) in the first quarter of 2018 (Point Topic, 2018), with forecast annual global growth slowing from 7% in 2017 (ITU, 2018) to 3% in 2022 (Point Topic, 2016). Overall the energy use in the network active state is projected to increase by 65% from 2018 to 2030.

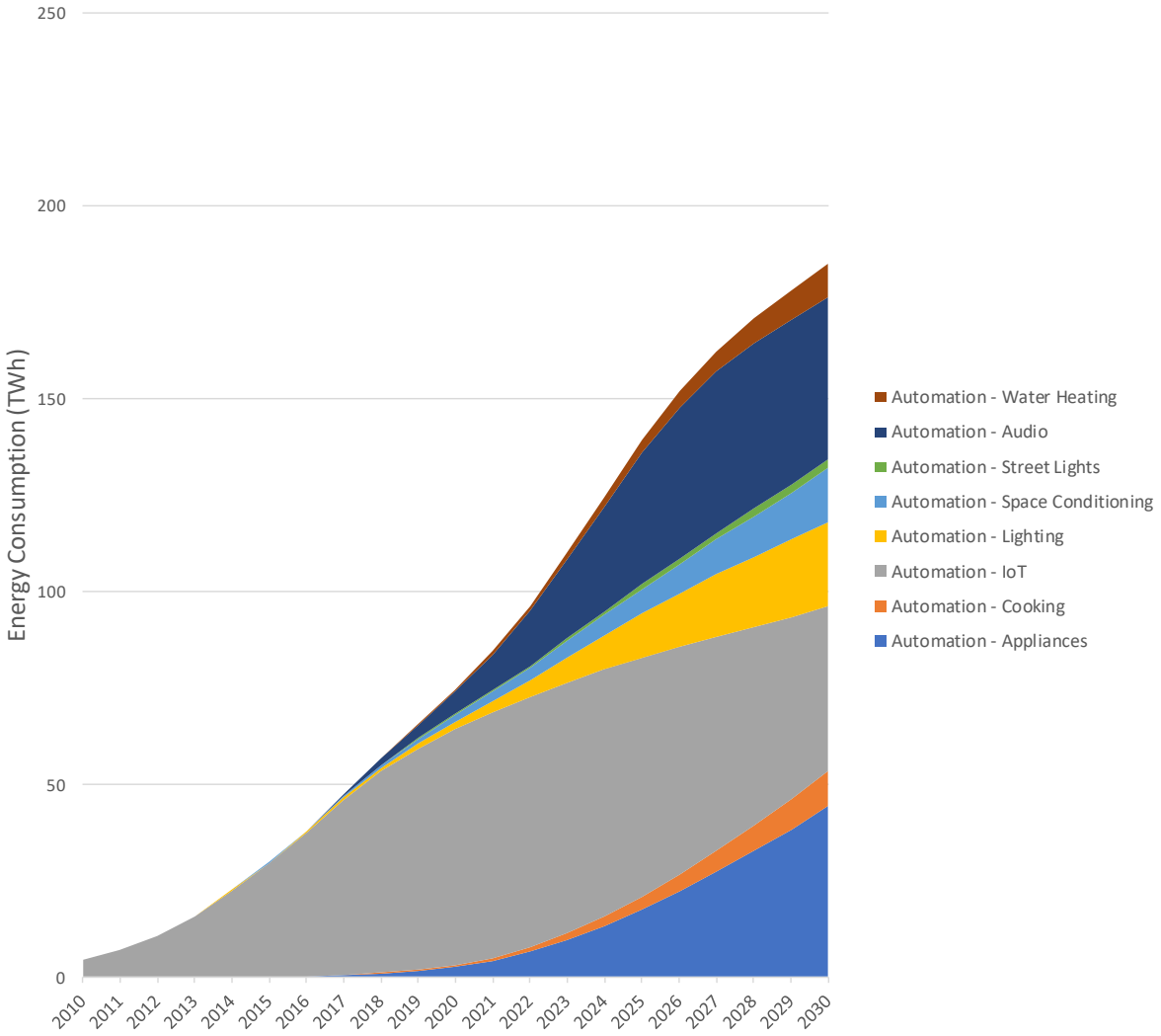
5.3 Network standby energy use of connected devices by categories

The following section provides more detail on the network standby energy consumption of connected devices. The key categories of automation and entertainment devices are examined in detail.

5.3.1 Network-connected automation devices

The network standby energy consumption by groups of automation devices is shown in Figure 19.

Figure 19: Automation devices: network standby energy consumption 2010 - 2030



Overall, the most significant groups in terms of network standby energy consumption are:

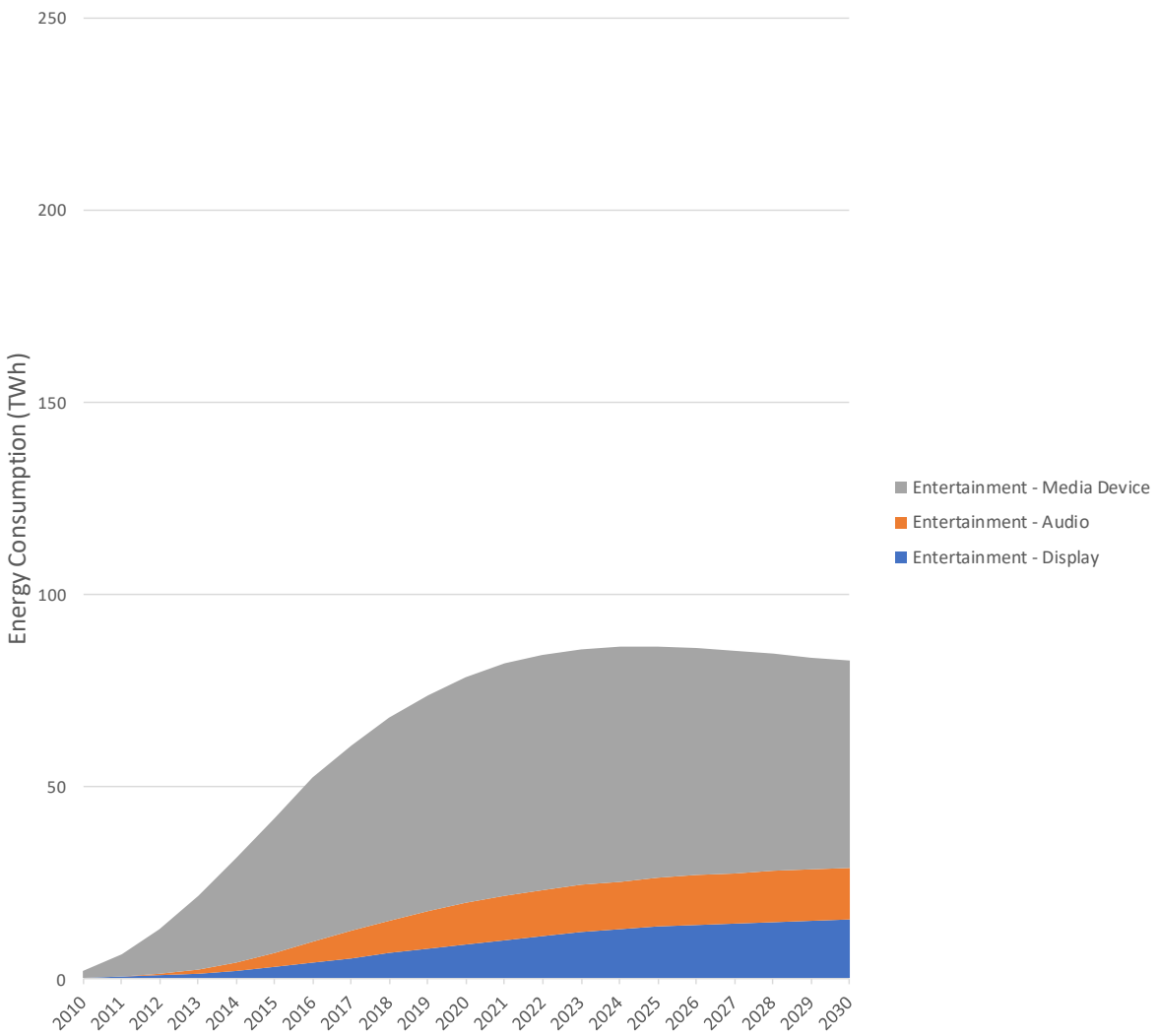
- Audio – which is voice assistant speakers, such as the Amazon Echo and Google Home. The network standby energy consumption for this group is projected to grow from 2 TWh in 2018 to 42 TWh in 2030.
- IoT – which includes most of the residential building sensors/controls/gateways, commercial building sensors/controls/gateways and utility smart meters. The network standby energy consumption for this group is estimated to be 52 TWh in 2018, and projected to decline to 43 TWh in 2030. The TEM assumes that many of these devices will use low power networks such as LoRaWAN, BLE, Zigbee, and NB-IoT, for communications from 2020 to 2030 (IHS Markit IHS, 2018; ON World, 2018). These low power networks have inherently lower network standby (Li *et al.*, 2017; Xergy Consulting, 2018).
- Home appliances – which includes whitegoods and other home small appliances are projected to increase their network standby energy use from 1 TWh in 2018 to 44 TWh in 2030.

The most significant increase in network standby energy use is mostly due to connected automation devices. Many of these devices are using Wi-Fi networks (802.11) for communication, which typically have higher network standby power levels (EDNA, 2016, 2018; Xergy Consulting, 2018). These automation devices typically include voice assistant speakers, connected home appliances and connected lighting (although there are now lighting products that are coming to the market and connect with low power networks).

5.3.2 Network-connected entertainment devices

The network standby energy consumption by groups of connected entertainment devices is shown in Figure 20.

Figure 20: Entertainment devices: network standby energy consumption 2010 - 2030



Overall, the most significant groups in terms of network standby energy consumption are:

- Media devices – which includes STBs, OTT media players and games consoles. The network standby energy consumption for this group is projected to grow to 62 TWh in 2022 and decline to 54 TWh in 2030. This is mainly due to the substitution of STB/OTT

with connected smart TVs, which are enabled to provide many of the video streaming services.

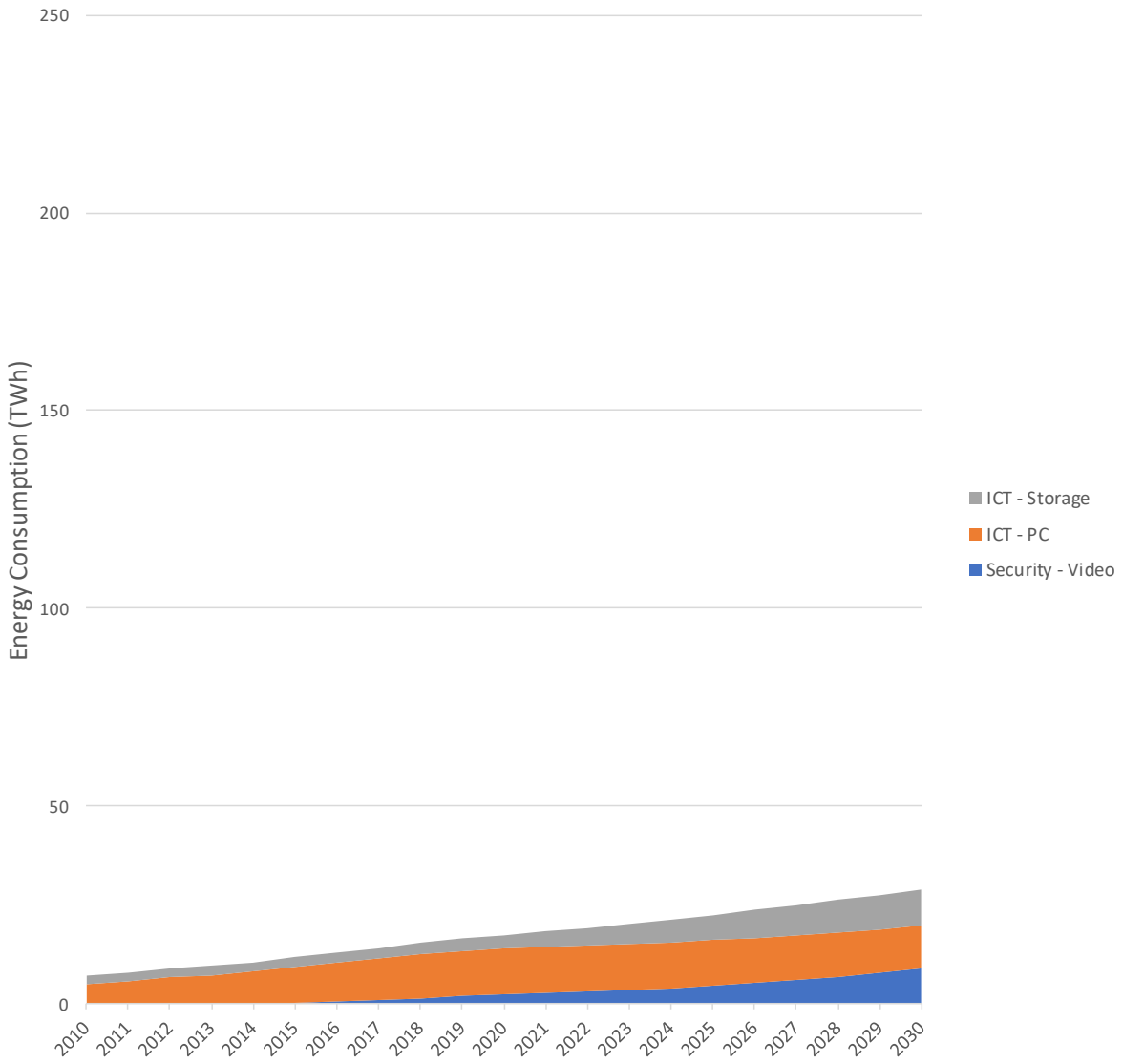
- Audio and Display – which includes connected AV speakers/receivers (Audio group) and smart TVs (Display group). While smart TVs are projected to increase in stock, their average network standby power consumption is relatively low (under 1W)(EDNA, 2018).

Network standby is significant for STBs and OTT media devices, while games consoles also contribute to the increasing network standby energy consumption for this group.

5.3.3 Network-connected ICT and security devices

The two smaller sub-groups of devices in terms of their network standby energy consumption are shown in Figure 21.

Figure 21: ICT and security devices: network standby energy consumption 2010 - 2030



The storage group includes network attached storage (NAS). The PC group covers desktop and laptop PCs, while IP cameras are the main devices in the security - video group. As the figure shows, network standby is growing significantly with NAS and IP camera devices.

Many battery powered devices use minimal energy in network standby state, as they have implemented power management strategies to ensure that battery life is extended. These devices are network-connected and included in the TEM, but their network standby energy use is not significant enough to be reported in these output figures. These device types include for example smart phones, tablets, health sensors, smart locks, portable speakers, and battery powered sensors.

5.4 Network active energy use of connected devices

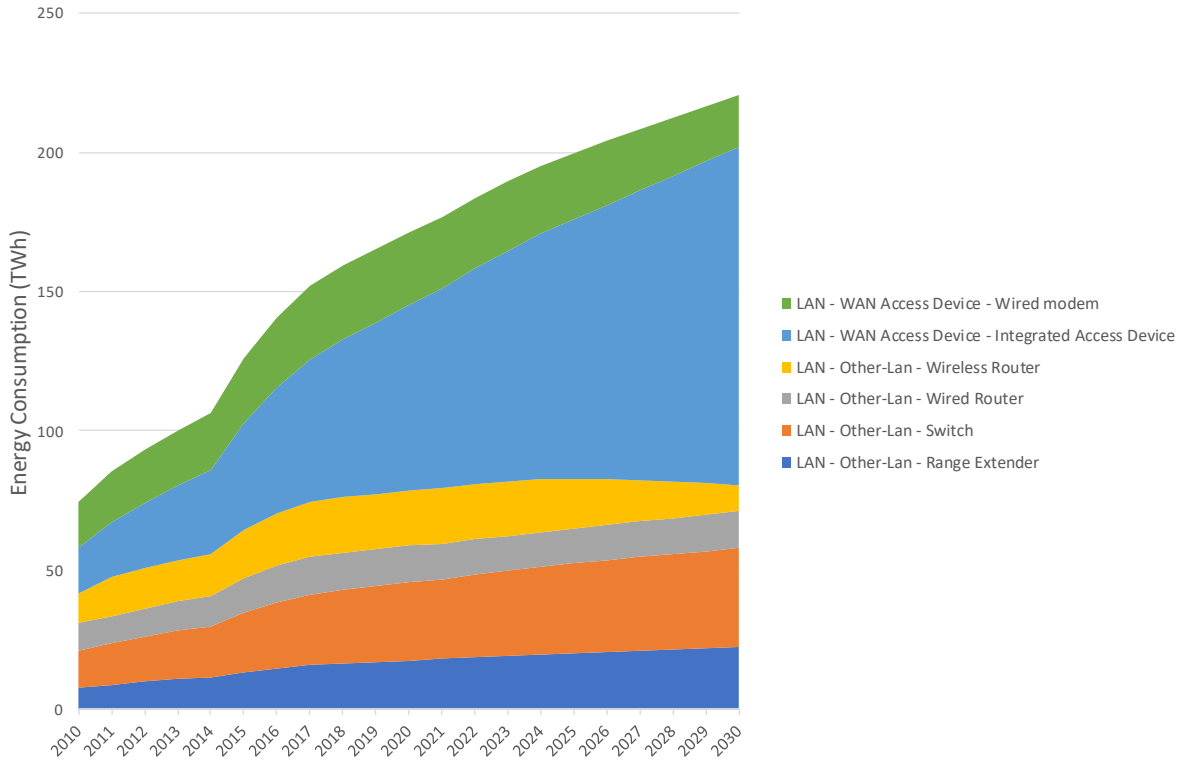
As previously shown in Figure 18, the majority of the energy consumption in network active state is attributed to LAN equipment, comprising 75% of the network active energy consumption in 2018 and projected to decrease to 62% of the network active energy consumption in 2030. However on an absolute level netowrk active energy consumption is increasing over the modelling period. Therefore the following section of the report describes only the energy use by LAN equipment in network active state.

5.4.1 LAN Equipment

The TEM has classified LAN equipment in network active state, as this is the condition that is used for defining the scope of energy use for LAN equipment in the earlier IEA reports (Harrington and Nordman, 2014). The EU has implemented networked[10] standby regulation that includes these devices in the scope (European Commission, 2013). The TEM assumes that all these devices are in the network active state when connected to networks. Therefore, it is important to identify the projected network active energy consumption of LAN equipment. Figure 22 shows the network active energy consumption by device and category (WAN access device, and other LAN).

[10] The EU policy, Commission Regulation (EU) No 801/2013, defines "networked standby" to specifically denote network devices that are capable of a low power mode with network connectivity.

Figure 22: LAN Equipment: network active energy consumption 2010 - 2030

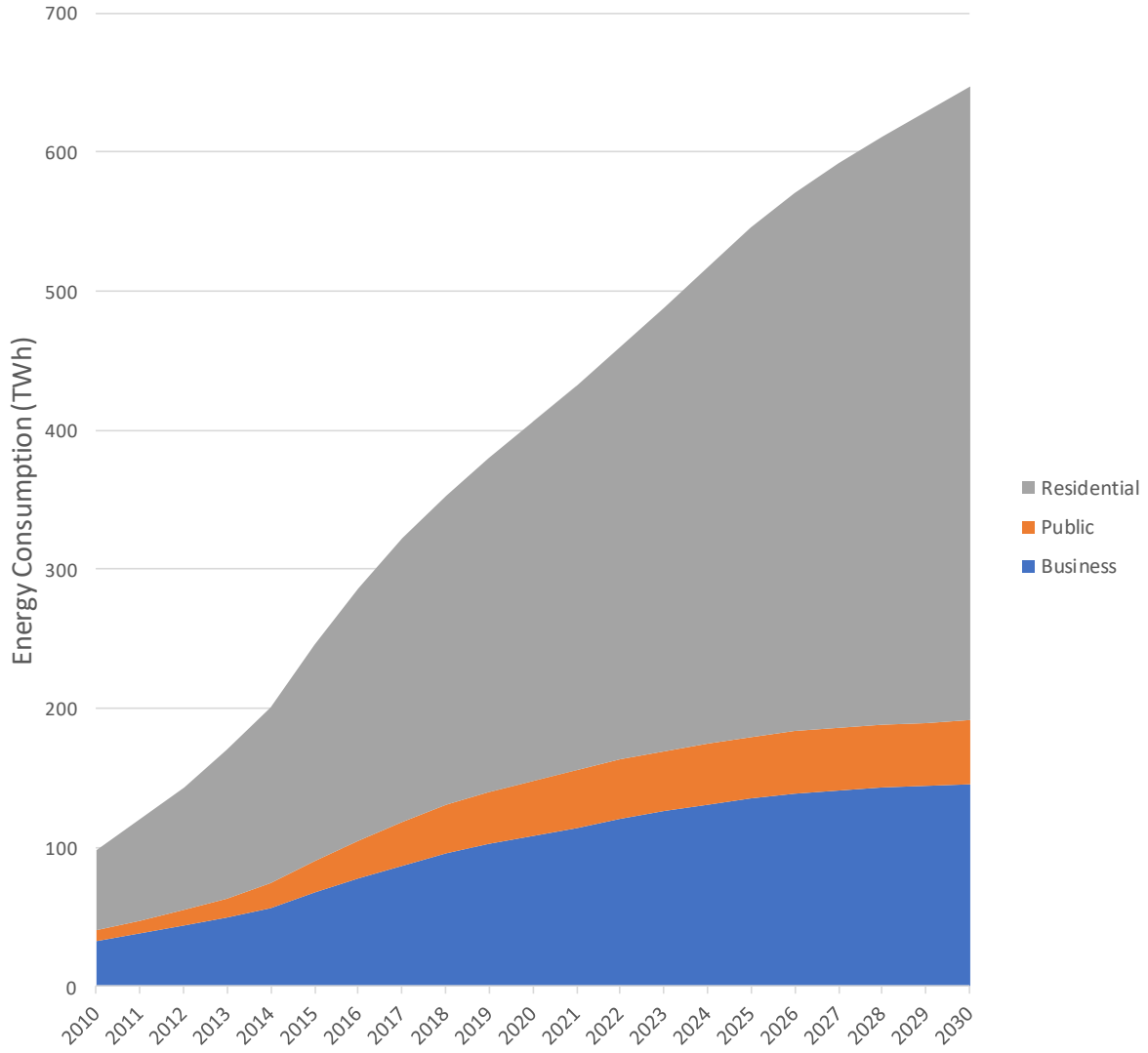


The growth of network active energy consumption by integrated access devices (IAD) is particularly significant, from 57 TWh in 2018 to 121 TWh in 2030. To provide a comparison, the total upstream energy use for WAN is estimated to be 175 TWh in 2018 and 139 TWh in 2030. Therefore, the network active energy use of just IADs is projected to be similar to the total energy use of the WAN/Core IP network in 2030. In addition, the total network active energy use of all types of LAN equipment is estimated to be larger than the energy used for WAN in 2018.

5.5 Network-connected energy use of devices by sector

Total network-connected energy consumption of edge devices by sector is shown in Figure 23. The total energy consumption of edge devices includes both network standby and active state, and includes the LAN equipment. Total network-connected energy consumption of edge devices and LAN equipment is projected to increase from 353 TWh in 2018 to 647 TWh in 2030.

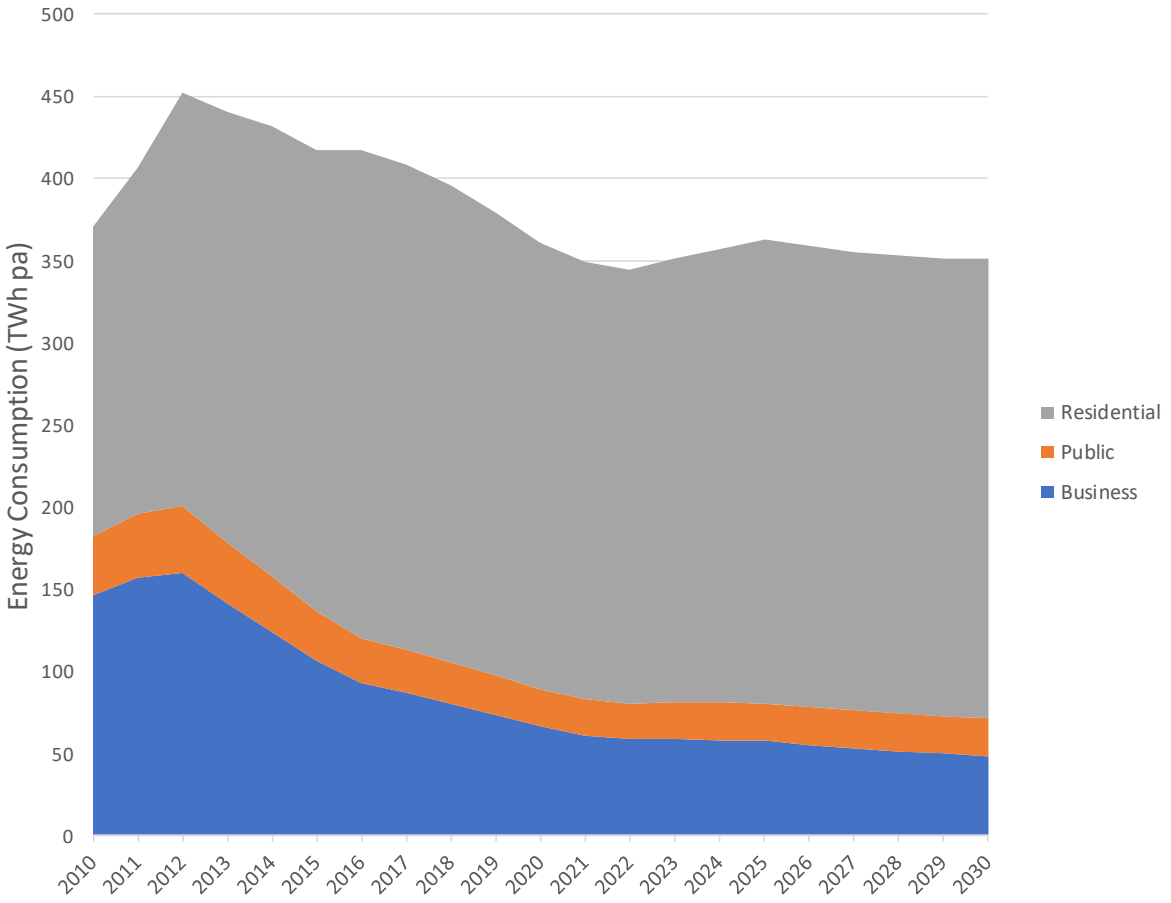
Figure 23: Network-connected energy consumption of edge and LAN devices by sector 2010 – 2030



The networked connected energy consumption of devices in the residential sector is projected to double from 223 TWh in 2018 to 456 TWh in 2030.

The total upstream network-connected energy consumption is projected to decline from 396 TWh in 2018 to 351 TWh in 2030, as shown in Figure 24.

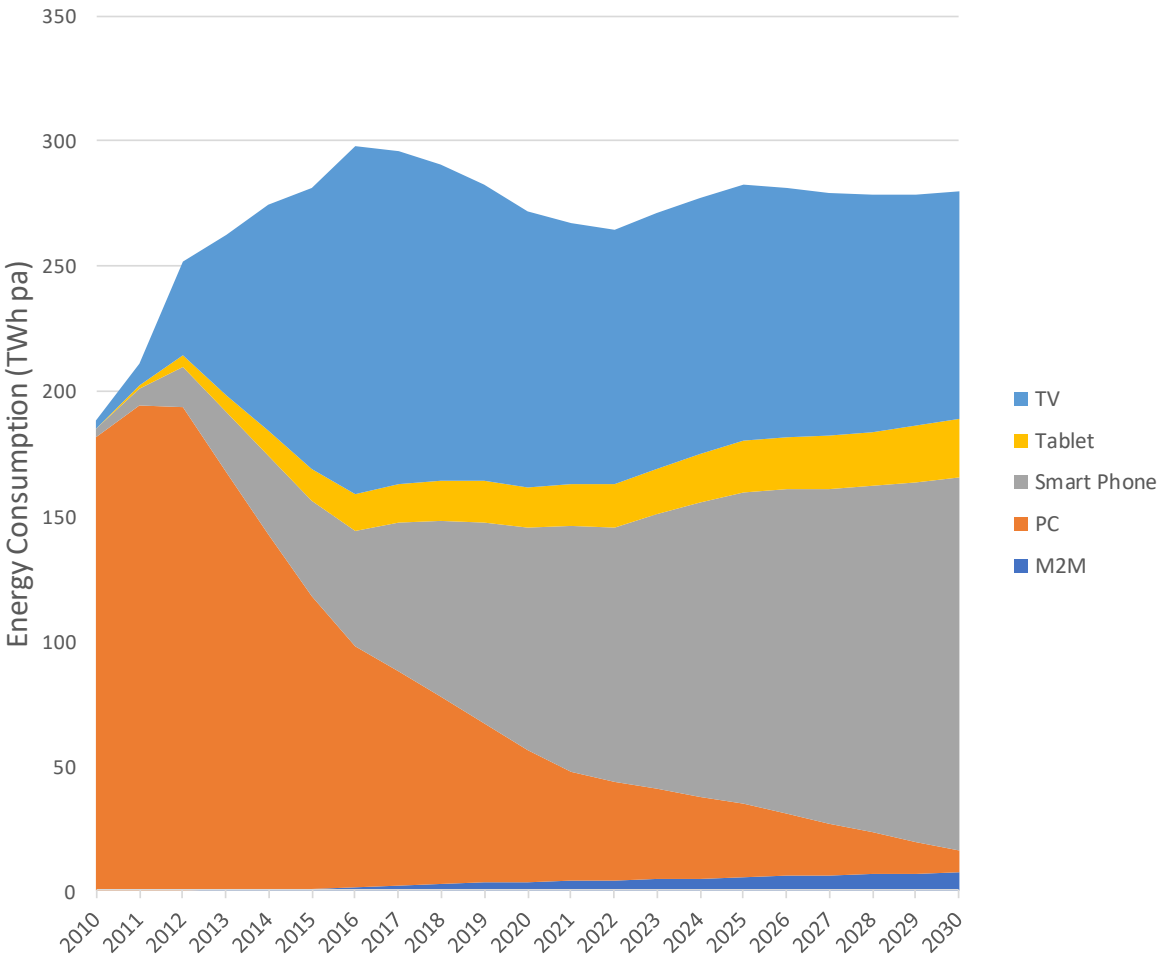
Figure 24: Upstream network energy consumption by sector 2010 – 2030



The residential sector's share of the additional upstream network energy consumption has increased from 50% in 2010 to 73% in 2018, and is projected to increase to 80% by 2030.

The residential total upstream network energy consumption by IP category is shown in Figure 25.

Figure 25: Residential upstream network energy consumption by IP Category: 2010 – 2030



This figure shows that PC device IP data related upstream network energy consumption is declining as TV and smart phone IP data related upstream network energy use is increasing. This trend closely matches the increasing data demand driven by video applications in TV/media devices and smart phone devices. The IP categories shown in the figure are used by CISCO as a way to segment the data traffic associated with similar uses (CISCO, 2018).

6 Conclusions and observations

This section presents the key observations from the research and outputs of the TEM that might inform the development of energy efficiency policy relating to network-connected devices.

Network standby energy use is growing

As the results from the TEM show, network standby related energy use of connected devices is projected to grow from 64 TWh in 2014 (0.3% share of total electricity demand) to 300 TWh in 2030 or 1% of total electricity demand.

The most significant factor driving this increase is the increasing number of connected devices, particularly those devices with significant power consumption in network standby state.

Policy action, such as the EU Ecodesign Directive addressing networked standby (European Commission, 2013) requirements and the energy efficiency voluntary agreements [11] relating to Complex Set-Top Boxes, Games Consoles and Imaging Equipment, are a key aspect of reducing network standby energy consumption. The global efforts in this area are increasing, but more work will be required to ensure effective policy outcomes. Some of the key products that appear to be increasing global network standby energy use are:

- Voice assistant speakers (average of 2.8W network standby power)
- Wi-Fi connected IoT devices and other Wi-Fi connected appliances (average of 2.5W network standby power)
- Media devices, such as STBs and OTT media players (average of 10.5W network standby power)

LAN Equipment energy use is increasing

The proportion energy use by LAN equipment is significant, representing 45% of all network-connected energy use by edge devices and the LAN in 2018. The active network energy use of the LAN equipment is estimated to be higher than WAN energy use in 2018. The growth in network active energy consumption by integrated access devices (IAD) is particularly significant, growing from 57 TWh in 2018 to 121 TWh in 2030. Power scaling and lowering network active energy use by these devices could make a considerable impact on reducing global network-connected energy consumption.

Network connection impacts on network standby energy consumption

The type of network connection impacts on the size of network standby energy consumption by devices according to earlier EDNA reports (Xergy Consulting, 2018). This report explains that network standby power consumption of standard Wi-Fi (802.11n) network-connected devices is higher than low power consumption wireless network connections such as Bluetooth, Zigbee and LPWAN. It appears that choice of device network connection by manufacturers is influenced by both technical and market factors. The most significant market factor is the widespread availability of Wi-Fi networks, which enables devices and appliances to be easily connected to the network.

[11] https://ec.europa.eu/energy/sites/ener/files/documents/list_eco-design-voluntary_agreements.pdf

Low power wireless networks require a gateway or bridge to connect to the internet, or a LPWAN service provider, and are less suitable for low latency and high bandwidth requirements (such as video). However, a large number of devices are technically suitable to connect via these lower power wireless networks, including many connected appliances. New sites are being rolled out with low power wireless (such as street lighting[12]) due to the lower costs of technology suitable for these applications. Encouraging the deployment of low power wireless networks for connected devices, instead of readily available and higher power using Wi-Fi network connections, would reduce network-connected energy use.

Multi-function connected devices require further investigation and research

The scope of the TEM did not consider the additional energy consumption due to increasing functions of existing devices, as this required many additional assumptions and creates uncertainty of what network-connected energy consumption is included. For instance, a refrigerator that is network-connected may have a display device that is now included in the door of the appliance and the TEM does not include the energy consumption of this display device. However, because the refrigerator is now connected to a network, the additional energy used by the display device could be assessed as within the scope of this study, as it is only present because of the network connection. The research conducted for this study found that these multi-function network-connected devices may be increasingly available in the market. The TEM could be updated regularly to account for multi-function network-connected devices and research conducted to inform policy approaches that include these devices. Examples of these multi-function devices that are not specifically included in the TEM and require more research to study their impacts include:

- Multi-function integrated/access points and mesh wireless routers – with voice assistant speakers or connected speakers
- Connected TVs and other appliances with voice assistant speakers
- Addition of displays to connected whitegoods, such as refrigerators and the impact of this on network standby
- Connected lights with speakers, which provide a simple method of establishing whole home audio

[12] https://iot-analytics.com/top-10-cities-implementing-connected-streetlights/

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Appendix A: TEM connected devices – calculations and assumptions

Device characteristics by category, and sales calculation source

Note the definitions below are used in the tables

Power Source

- Battery Small - BS
- Battery Rechargeable - BR
- Mains Power - MP
- Solar - Solar

Network Connection type

- Bluetooth - BT
- Wireless - Wi-Fi
- Zigbee - ZB
- Wired
- Mobile Network – MN, 3G,4G
- Low power WAN - LPWAN

Table 2 LAN Equipment – multi sector

EDNA Category	IP Category	Sector	Segment	Category	Group	Device	Power Source	Network Connection	Sales Calculation
LAN	LAN	Residential		LAN	WAN Access Device	Integrated Access Device	MP	Wi-Fi/wired	Stock Estimate + Device Share
LAN	LAN	Residential		LAN	WAN Access Device	Wired modem	MP	Wired	Stock Estimate + Device Share
LAN	LAN	Residential		LAN	WAN Access Device	Wireless Modem Router	MP	Wireless - 3G/4G/Wi-Fi	Stock Estimate + Device Share
LAN	LAN	Residential		LAN	Other-Lan	Wireless Router	MP	Wi-Fi/wired	Stock Estimate + Device Share
LAN	LAN	Residential		LAN	Other-Lan	Wired Router	MP	Wired	Stock Estimate + Device Share
LAN	LAN	Residential		LAN	Other-Lan	Switch	MP	Wired	Stock Estimate + Device Share
LAN	LAN	Residential		LAN	Other-Lan	Range Extender	MP	Wi-Fi	Stock Estimate + Device Share
LAN	LAN	Business		LAN	WAN Access Device	Integrated Access Device	MP	Wi-Fi/wired	Stock Estimate + Device Share
LAN	LAN	Business		LAN	WAN Access Device	Wired modem	MP	Wired	Stock Estimate + Device Share
LAN	LAN	Business		LAN	WAN Access Device	Wireless Modem Router	MP	Wireless - 3G/4G/Wi-Fi	Stock Estimate + Device Share
LAN	LAN	Business		LAN	Other-Lan	Wireless Router	MP	Wi-Fi/wired	Stock Estimate + Device Share
LAN	LAN	Business		LAN	Other-Lan	Wired Router	MP	Wired	Stock Estimate + Device Share
LAN	LAN	Business		LAN	Other-Lan	Switch	MP	Wired	Stock Estimate + Device Share
LAN	LAN	Business		LAN	Other-Lan	Range Extender	MP	Wi-Fi	Stock Estimate + Device Share
LAN	LAN	Public		LAN	WAN Access Device	Integrated Access Device	MP	Wi-Fi/wired	Stock Estimate + Device Share
LAN	LAN	Public		LAN	WAN Access Device	Wired modem	MP	Wired	Stock Estimate + Device Share
LAN	LAN	Public		LAN	WAN Access Device	Wireless Modem Router	MP	Wireless - 3G/4G/Wi-Fi	Stock Estimate + Device Share
LAN	LAN	Public		LAN	Other-Lan	Wireless Router	MP	Wi-Fi/wired	Stock Estimate + Device Share
LAN	LAN	Public		LAN	Other-Lan	Wired Router	MP	Wired	Stock Estimate + Device Share
LAN	LAN	Public		LAN	Other-Lan	Switch	MP	Wired	Stock Estimate + Device Share
LAN	LAN	Public		LAN	Other-Lan	Range Extender	MP	Wi-Fi	Stock Estimate + Device Share

Table 3 Residential sector equipment

EDNA Category	IP Category	Sector	Segment	Category	Group	Device	Power Source	Network Connection	Sales Calculation
Edge-D	PC	Residential	Residential	ICT	PC	Desktop	MP	Wi-Fi/wired	Sales + Sector Share
Edge-D	PC	Residential	Residential	ICT	PC	Laptop PC	BR	Wi-Fi/wired	Sales + Sector Share
Edge-D	SmartPhone	Residential	Residential	ICT	Mobile	Smart Phone	BR	Wi-Fi, MN	Sales + Sector Share
Edge-D	Non-Smart Phone	Residential	Residential	ICT	Mobile	Phone - not smart	BR	2/3G	Sales + Sector Share
Edge-D	Tablets	Residential	Residential	ICT	Tablet	Tablet	BR	Wi-Fi, MN	Sales + Sector Share
Edge-D	PC	Residential	Residential	ICT	Storage	NAS	MP	Wi-Fi/wired	Sales + Sector Share
Edge-D	PC	Residential	Residential	ICT	PC	Imaging Equipment	MP	Wi-Fi/wired	Sales + Sector Share
Edge-D	TV	Residential	Residential	Entertainment	Display	Smart TV	MP	Wi-Fi/wired	Sales + Network Connection Share
Edge-O	TV	Residential	Residential	Entertainment	Audio	AV Reciever	MP	Wi-Fi/wired	Sales
Edge-D	TV	Residential	Residential	Entertainment	Audio	AV Speakers	MP	Wi-Fi/BT	Sales
Edge-D	SmartPhone	Residential	Residential	Entertainment	Audio	Portable Speakers	BR	Wi-Fi/BT	Sales
Edge-D	M2M	Residential	Residential	Automation	Audio	VA Speaker	MP	Wi-Fi/BT	Sales
Edge-D	TV	Residential	Residential	Entertainment	Media Device	Games Console	MP	Wi-Fi/wired	Sales + Network Connection Share
Edge-D	TV	Residential	Residential	Entertainment	Media Device	STB & OTT Media Player	MP	Wi-Fi/wired	Sales
Edge-O	M2M	Residential	Residential	Automation	Lighting	Smart Lights - Wifi	MP	Wi-Fi	Sales
Edge-O	M2M	Residential	Residential	Automation	Lighting	Smart Lights - LE	MP	ZB/BT	Sales
Edge-D	M2M	Residential	Residential	Automation	IoT	Gateway - LE to Wi-Fi	MP	Wi-Fi/wired	Sales
Edge-D	M2M	Residential	Residential	Security	Video	IP Camera - Home	MP	Wi-Fi/wired	Sales
Edge-D	M2M	Residential	Residential	Security	Control	Smart Lock	BR	ZB/BT	Sales
Edge-D	M2M	Residential	Residential	Automation	IoT	Sensors: Res - LE	BS	BT/ZB	Sales
Edge-D	M2M	Residential	Residential	Automation	IoT	Sensors: Res - Wi-Fi	MP	Wi-Fi/BT/ZB	Sales
Edge-O	M2M	Residential	Residential	Automation	IoT	Blinds + Windows	BS	BT/ZB	Sales
Edge-D	M2M	Residential	Residential	Automation	Space Conditioning	Smart Thermostat	MP	Wi-Fi/BT/ZB	Sales
Edge-O	M2M	Residential	Residential	Automation	Space Conditioning	Air Conditioners	MP	Wi-Fi	Sales Direct Entry by Region
Edge-O	M2M	Residential	Residential	Automation	Water Heating	Water Heaters	MP	Wi-Fi/BT/ZB	Parent Stock + Network Connection Share of Sales

EDNA Category	IP Category	Sector	Segment	Category	Group	Device	Power Source	Network Connection	Sales Calculation
Edge-O	M2M	Residential	Residential	Automation	Appliances	Refrigerator	MP	Wi-Fi	Parent Stock + Network Connection Share of Sales
Edge-O	M2M	Residential	Residential	Automation	Appliances	Freezer	MP	Wi-Fi	Parent Stock + Network Connection Share of Sales
Edge-O	M2M	Residential	Residential	Automation	Appliances	Washing Machine	MP	Wi-Fi	Parent Stock + Network Connection Share of Sales
Edge-O	M2M	Residential	Residential	Automation	Appliances	Clothes Dryer	MP	Wi-Fi	Parent Stock + Network Connection Share of Sales
Edge-O	M2M	Residential	Residential	Automation	Appliances	Dishwasher	MP	Wi-Fi	Parent Stock + Network Connection Share of Sales
Edge-O	M2M	Residential	Residential	Automation	Cooking	Oven + Cooktop	MP	Wi-Fi	Parent Stock + Network Connection Share of Sales
Edge-O	M2M	Residential	Residential	Automation	Cooking	Range Hood	MP	BT	Sales
Edge-O	M2M	Residential	Residential	Automation	Appliances	Small Appliance	MP	Wi-Fi	Sales

Table 4 Business sector equipment

EDNA Category	IP Category	Sector	Segment	Category	Group	Device	Power Source	Network Connection	Sales Calculation
Edge-D	PC	Business		ICT	PC	Desktop	MP	Wi-Fi/wired	Sales + Sector Share
Edge-D	PC	Business		ICT	PC	Laptop PC	BR	Wi-Fi/wired	Sales + Sector Share
Edge-D	SmartPhone	Business		ICT	Mobile	Smart Phone	BR	Wi-Fi, MN	Sales + Sector Share
Edge-D	Non-Smart Phone	Business		ICT	Mobile	Phone - not smart	BR	2/3G	Sales + Sector Share
Edge-D	Tablets	Business		ICT	Tablet	Tablet	BR	Wi-Fi, MN	Sales + Sector Share
Edge-D	PC	Business		ICT	Storage	NAS	MP	Wi-Fi/wired	Sales + Sector Share
Edge-D	M2M	Business		Security	Video	IP Camera - Public + Business	MP	Wi-Fi, MN	Sales + Sector Share
Edge-D	M2M	Business	Manufacturing	Automation	IoT	Sensors: Industry - LE	BR	LPWAN, LELAN	Sales
Edge-D	M2M	Business	Manufacturing	Automation	IoT	Gateway: Bus	MP	Wi-Fi, Wired	Sales
Edge-D	M2M	Business		Automation	IoT	Comm Building Control	MP	Wi-Fi, Wired	Sales
Edge-D	TV	Business	Retail	Entertainment	Display	Digital Signage Display	MP	Wi-Fi, Wired	Sales
Edge-D	PC	Business		ICT	PC	Imaging Equipment	MP	Wi-Fi/wired	Sales + Sector Share

Table 5 Public sector equipment

EDNA Category	IP Category	Sector	Segment	Category	Group	Device	Power Source	Network Connection	Sales Calculation
Edge-D	PC	Public		ICT	PC	Desktop	MP	Wi-Fi/wired	Sales + Sector Share
Edge-D	PC	Public		ICT	PC	Laptop PC	BR	Wi-Fi/wired	Sales + Sector Share
Edge-D	SmartPhone	Public		ICT	Mobile	Smart Phone	BR	Wi-Fi, MN	Sales + Sector Share
Edge-D	Non-Smart Phone	Public		ICT	Mobile	Phone - not smart	BR	2/3G	Sales + Sector Share
Edge-D	Tablets	Public		ICT	Tablet	Tablet	BR	Wi-Fi, MN	Sales + Sector Share
Edge-D	PC	Public		ICT	Storage	NAS	MP	Wi-Fi/wired	Sales + Sector Share
Edge-O	M2M	Public	Smart Cities	Automation	Street Lights	Street Lights	MP	Wi-Fi, LPWAN	Parent Stock + Network Connection Share of Sales
Edge-D	M2M	Public	Smart Cities	Security	Video	IP Camera - Public + Business	MP	Wi-Fi, MN	Sales + Sector Share
Edge-D	M2M	Public	Health	Automation	IoT	Sensors: Health - LE	BR	LPWAN, LELAN	Sales
Edge-D	M2M	Public	Utilities	Automation	IoT	Smart Meters	MP	2/3G/5G LPWAN	Sales
Edge-D	PC	Public		ICT	PC	Imaging Equipment	MP	Wi-Fi/wired	Sales + Sector Share

Table 6 presents the active and standby power use for each device in the TEM (in watts) and the percentage annual change pre-2017 and post-2017 for both network states. These changes are applied to the power consumption so that trends over time are captured by the equipment installed in that particular year. The input values are estimated sales weighted average power, however product/model weighted values are used where this is not available.

Table 6: Average active and standby network power of devices and trends pre and post 2017.

Sector	Segment	Category	Group	Device	Network Active [W]	Pre 2017 change	Post 2017	Network Standby [W]	Pre 2017	Post 2017
Residential	Residential	LAN	WAN Access Device	Integrated Access Device	13.5	3.0%	0.5%			
Residential	Residential	LAN	WAN Access Device	Wired modem	7.1	1.0%	0.5%			
Residential	Residential	LAN	WAN Access Device	Wireless Modem Router	6	3.0%	0.0%			
Residential	Residential	LAN	Other-Lan	Wireless Router	10	0.5%	1.0%			
Residential	Residential	LAN	Other-Lan	Wired Router	6	0.0%	0.0%			
Residential	Residential	LAN	Other-Lan	Switch	6	0.0%	0.0%			
Residential	Residential	LAN	Other-Lan	Range Extender	8	0.0%	0.0%			
Business		LAN	WAN Access Device	Integrated Access Device	13.5	3.0%	0.5%			
Business		LAN	WAN Access Device	Wired modem	7.1	1.0%	0.5%			
Business		LAN	WAN Access Device	Wireless Modem Router	6	3.0%	0.0%			
Business		LAN	Other-Lan	Wireless Router	10	0.5%	1.0%			
Business		LAN	Other-Lan	Wired Router	6	0.0%	0.0%			
Business		LAN	Other-Lan	Switch	6	0.0%	0.0%			
Business		LAN	Other-Lan	Range Extender	8	0.0%	0.0%			
Public		LAN	WAN Access Device	Integrated Access Device	13.5	3.0%	0.5%			
Public		LAN	WAN Access Device	Wired modem	7.1	1.0%	0.5%			
Public		LAN	WAN Access Device	Wireless Modem Router	6	3.0%	0.0%			
Public		LAN	Other-Lan	Wireless Router	10	0.5%	1.0%			
Public		LAN	Other-Lan	Wired Router	6	0.0%	0.0%			
Public		LAN	Other-Lan	Switch	6	0.0%	0.0%			
Public		LAN	Other-Lan	Range Extender	8	0.0%	0.0%			
Residential	Residential	ICT	PC	Desktop	2.2	-3.0%	0.0%	2		
Residential	Residential	ICT	PC	Laptop PC	1	-3.0%	0.0%	0.7	-3.0%	0.0%
Residential	Residential	ICT	Mobile	Smart Phone	0.513699	0.0%	0.0%		0.0%	0.0%
Residential	Residential	ICT	Mobile	Phone - not smart	0	0.0%	0.0%		0.0%	0.0%
Residential	Residential	ICT	Tablet	Tablet	0.696347	0.0%	0.0%		0.0%	0.0%

Sector	Segment	Category	Group	Device	Network Active [W]	Pre 2017 change	Post 2017	Network Standby [W]	Pre 2017	Post 2017
Residential	Residential	ICT	Storage	NAS	20	-5.0%	-2.0%	15	-5.0%	-2.0%
Residential	Residential	ICT	PC	Imaging Equipment	3	-5.0%	-2.0%	3	-5.0%	-2.0%
Residential	Residential	Entertainment	Display	Smart TV	3	0.0%	0.0%	1	0.0%	0.0%
Residential	Residential	Entertainment	Audio	AV Receiver	4.3	0.0%	0.0%	4.3	0.0%	0.0%
Residential	Residential	Entertainment	Audio	AV Speakers	3.5	0.0%	0.0%	3.5	0.0%	0.0%
Residential	Residential	Entertainment	Audio	Portable Speakers	0.11	0.0%	0.0%	0.11	0.0%	0.0%
Residential	Residential	Automation	Audio	VA Speaker	3.34	0.0%	1.0%	2.84	0.0%	1.0%
Residential	Residential	Entertainment	Media Device	Games Console	5	-5.0%	-2.0%	5	-5.0%	-2.0%
Residential	Residential	Entertainment	Media Device	STB & OTT Media Player	12.5	-5.0%	-0.5%	10.5	-5.0%	-1.0%
Residential	Residential	Automation	Lighting	Smart Lights - Wi-Fi	2	-5.0%	-0.5%	2	-5.0%	-1.0%
Residential	Residential	Automation	Lighting	Smart Lights - LE	0.44	-5.0%	-0.5%	0.44	-5.0%	-1.0%
Residential	Residential	Automation	IoT	Gateway - LE to Wi-Fi	1.4	-5.0%	-0.5%	1.4	-5.0%	-1.0%
Residential	Residential	Security	Video	IP Camera - Home	2	-5.0%	-0.5%	2	-5.0%	-0.5%
Residential	Residential	Security	Control	Smart Lock	0.001	-5.0%	-0.5%	0.001	-5.0%	-0.5%
Residential	Residential	Automation	IoT	Sensors: Res - LE	0.001	0.0%	0.0%	0.001	0.0%	0.0%
Residential	Residential	Automation	IoT	Sensors: Res - Wi-Fi	1.2	0.0%	0.0%	1.2	0.0%	0.0%
Residential	Residential	Automation	IoT	Blinds + Windows	0.001	-5.0%	-0.5%	0.001	-5.0%	-0.5%
Residential	Residential	Automation	Space Conditioning	Smart Thermostat	1.77	-8.0%	-0.5%	1.77	-8.0%	-0.5%
Residential	Residential	Automation	Space Conditioning	Air Conditioners	1.77	-8.0%	-0.5%	1.77	-8.0%	-0.5%
Residential	Residential	Automation	Water Heating	Water Heaters	2	-8.0%	-0.5%	2	-8.0%	-0.5%
Residential	Residential	Automation	Appliances	Refrigerator	15	0.0%	5.0%	2.5	0.0%	-0.5%
Residential	Residential	Automation	Appliances	Freezer	2.5	-5.0%	-0.5%	2.5	-5.0%	-0.5%
Residential	Residential	Automation	Appliances	Washing Machine	2.5	-5.0%	-0.5%	2.5	-5.0%	-0.5%
Residential	Residential	Automation	Appliances	Clothes Dryer	2.5	-5.0%	-0.5%	2.5	-5.0%	-0.5%
Residential	Residential	Automation	Appliances	Dishwasher	2.5	-5.0%	-0.5%	2.5	-5.0%	-0.5%
Residential	Residential	Automation	Cooking	Oven + Cooktop	2.5	-5.0%	-0.5%	2.5	-5.0%	-0.5%
Residential	Residential	Automation	Cooking	Range Hood	2.5	-5.0%	-0.5%	2.5	-5.0%	-0.5%
Residential	Residential	Automation	Appliances	Small Appliance	2.5	-5.0%	-0.5%	2.5	-5.0%	-0.5%

Sector	Segment	Category	Group	Device	Network Active [W]	Pre 2017 change	Post 2017	Network Standby [W]	Pre 2017	Post 2017
Business		ICT	PC	Desktop	2.2	-3.0%	0.0%	2	-3.0%	0.0%
Business		ICT	PC	Laptop PC	1	-3.0%	0.0%	0.7	-3.0%	0.0%
Business		ICT	Mobile	Smart Phone	0.51	0.0%	0.0%	0	0.0%	0.0%
Business		ICT	Mobile	Phone - not smart	0	0.0%	0.0%	0	0.0%	0.0%
Business		ICT	Tablet	Tablet	0.70	0.0%	0.0%	0	0.0%	0.0%
Business		ICT	Storage	NAS	20	-5.0%	-2.0%	15	-5.0%	-2.0%
Business		Security	Video	IP Camera - Public + Business	8	-5.0%	-2.0%	8	-5.0%	-2.0%
Business	Manufacturing	Automation	IoT	Sensors: Industry - LE	0.001	0.0%	0.0%	0.001	0.0%	0.0%
Business	Manufacturing	Automation	IoT	Gateway: Bus	7	-5.0%	-0.5%	7	-5.0%	-0.5%
Business		Automation	IoT	Comm Building Control	1.5	-5.0%	-20.0%	1.5	-5.0%	-20.0%
Business	Retail	Entertainment	Display	Digital Signage Display	3	0.0%	0.0%	1	0.0%	0.0%
Business		ICT	PC	Imaging Equipment	3	-5.0%	-2.0%	3	-5.0%	-2.0%
Public		ICT	PC	Desktop	2.2	-3.0%	0.0%	2	-3.0%	0.0%
Public		ICT	PC	Laptop PC	1	-3.0%	0.0%	0.7	-3.0%	0.0%
Public		ICT	Mobile	Smart Phone	0.513699	0.0%	0.0%	0	0.0%	0.0%
Public		ICT	Mobile	Phone - not smart	0	0.0%	0.0%	0	0.0%	0.0%
Public		ICT	Tablet	Tablet	0.696347	0.0%	0.0%	0	0.0%	0.0%
Public		ICT	Storage	NAS	20	-5.0%	-2.0%	15	-5.0%	-2.0%
Public	Smart Cities	Automation	Street Lights	Street Lights	1.5	-5.0%	-2.0%	1.5	-5.0%	-2.0%
Public	Smart Cities	Security	Video	IP Camera - Public + Business	8	-5.0%	-2.0%	8	-5.0%	-2.0%
Public	Health	Automation	IoT	Sensors: Health - LE	0.001	0.0%	0.0%	0.001	0.0%	0.0%
Public	Utilities	Automation	IoT	Smart Meters	2	-5.0%	-25.0%	2	-5.0%	-25.0%
Public		ICT	PC	Imaging Equipment	3	-5.0%	-2.0%	3	-5.0%	-2.0%

The average hours of operation for each network state were obtained from various sources, including (EDNA, 2016; EDNA 4E TCP, 2016; Fraunhofer, 2017), or estimated. For some devices the estimated hours were based on the assumption that the device was either in network standby or network active state for almost all the time. Table 7 shows the average hours of operation per day and the estimated average life.

Estimates of average service life are also obtained from external sources, including (Fraunhofer, 2017), or based on previous project work undertaken by EnergyConsult for regulators or government departments. The service life estimate entered into the TEM and reported in the following table is the years of life at which 50% of the products remain in service. The TEM implements a function to calculate the Survival at (the percentage of the products that are still in service) at each year following the installation. An example of a product with a 4 year average life (where 50% are remaining in service) is shown in the Figure 26.

Figure 26: TEM Survival function representing a 4 year average life for a device

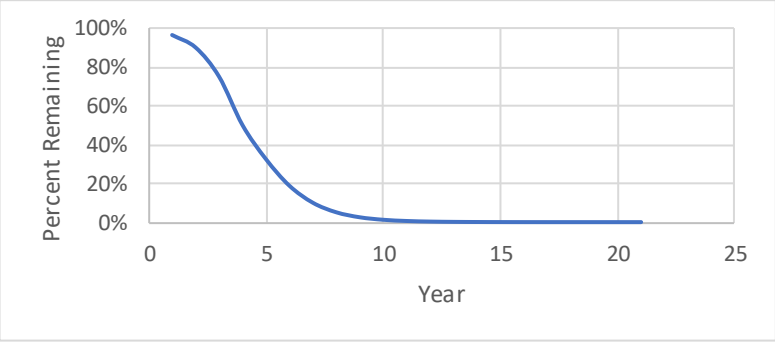

Table 7: Hours of operation by network state and estimated average life of network-connected devices as used in the TEM.

Sector	Segment	Category	Group	Device	Network Active [h]	Network Standby [h]	Average Life [year]
Residential	Residential	LAN	WAN Access Device	Integrated Access Device	24	0	5
Residential	Residential	LAN	WAN Access Device	Wired modem	24	0	7
Residential	Residential	LAN	WAN Access Device	Wireless Modem Router	24	0	5
Residential	Residential	LAN	Other-Lan	Wireless Router	24	0	5
Residential	Residential	LAN	Other-Lan	Wired Router	24	0	7
Residential	Residential	LAN	Other-Lan	Switch	24	0	7
Residential	Residential	LAN	Other-Lan	Range Extender	24	0	5
Business		LAN	WAN Access Device	Integrated Access Device	24	0	5
Business		LAN	WAN Access Device	Wired modem	24	0	7
Business		LAN	WAN Access Device	Wireless Modem Router	24	0	5
Business		LAN	Other-Lan	Wireless Router	24	0	5
Business		LAN	Other-Lan	Wired Router	24	0	7
Business		LAN	Other-Lan	Switch	24	0	7
Business		LAN	Other-Lan	Range Extender	24	0	5
Public		LAN	WAN Access Device	Integrated Access Device	24	0	5
Public		LAN	WAN Access Device	Wired modem	24	0	7
Public		LAN	WAN Access Device	Wireless Modem Router	24	0	5
Public		LAN	Other-Lan	Wireless Router	24	0	5
Public		LAN	Other-Lan	Wired Router	24	0	7
Public		LAN	Other-Lan	Switch	24	0	7
Public		LAN	Other-Lan	Range Extender	24	0	5
Residential	Residential	ICT	PC	Desktop	8.1	6.2	4
Residential	Residential	ICT	PC	Laptop PC	8.1	6.2	4
Residential	Residential	ICT	Mobile	Smart Phone	24	0	3

Sector	Segment	Category	Group	Device	Network Active [h]	Network Standby [h]	Average Life [year]
Residential	Residential	ICT	Mobile	Phone - not smart	24	0	5
Residential	Residential	ICT	Tablet	Tablet	24	0	3
Residential	Residential	ICT	Storage	NAS	1	23	5
Residential	Residential	ICT	PC	Imaging Equipment	0.5	23.5	5
Residential	Residential	Entertainment	Display	Smart TV	4	20	7
Residential	Residential	Entertainment	Audio	AV Reciever	4	20	7
Residential	Residential	Entertainment	Audio	AV Speakers	4	20	7
Residential	Residential	Entertainment	Audio	Portable Speakers	0	24	3
Residential	Residential	Automation	Audio	VA Speaker	2	22	4
Residential	Residential	Entertainment	Media Device	Games Console	1.5	22.5	5
Residential	Residential	Entertainment	Media Device	STB & OTT Media Player	3	21	5
Residential	Residential	Automation	Lighting	Smart Lights - Wifi	0	24	7
Residential	Residential	Automation	Lighting	Smart Lights - LE	0	24	7
Residential	Residential	Automation	IoT	Gateway - LE to Wi-Fi	24	0	7
Residential	Residential	Security	Video	IP Camera - Home	0	24	5
Residential	Residential	Security	Control	Smart Lock	0	24	5
Residential	Residential	Automation	IoT	Sensors: Res - LE	0	24	5
Residential	Residential	Automation	IoT	Sensors: Res - Wi-Fi	0	24	5
Residential	Residential	Automation	IoT	Blinds + Windows	0	24	5
Residential	Residential	Automation	Space Conditioning	Smart Thermostat	0	24	12
Residential	Residential	Automation	Space Conditioning	Air Conditioners	0	24	12
Residential	Residential	Automation	Water Heating	Water Heaters	0	24	12
Residential	Residential	Automation	Appliances	Refrigerator	2	22	12
Residential	Residential	Automation	Appliances	Freezer	0	24	12
Residential	Residential	Automation	Appliances	Washing Machine	0	24	12
Residential	Residential	Automation	Appliances	Clothes Dryer	0	24	12
Residential	Residential	Automation	Appliances	Dishwasher	0	24	12
Residential	Residential	Automation	Cooking	Oven + Cooktop	0	24	15

Sector	Segment	Category	Group	Device	Network Active [h]	Network Standby [h]	Average Life [year]
Residential	Residential	Automation	Cooking	Range Hood	0	24	4
Residential	Residential	Automation	Appliances	Small Appliance	0	24	4
Business		ICT	PC	Desktop	8.1	6.2	4
Business		ICT	PC	Laptop PC	8.1	6.2	4
Business		ICT	Mobile	Smart Phone	24	0	3
Business		ICT	Mobile	Phone - not smart	24	0	5
Business		ICT	Tablet	Tablet	24	0	3
Business		ICT	Storage	NAS	1	23	5
Business		Security	Video	IP Camera - Public + Business	24	0	10
Business	Manufacturing	Automation	IoT	Sensors: Industry - LE	0	24	5
Business	Manufacturing	Automation	IoT	Gateway: Bus	24	0	7
Business		Automation	IoT	Comm Building Control	0	24	12
Business	Retail	Entertainment	Display	Digital Signage Display	1	23	5
Business		ICT	PC	Imaging Equipment	0.5	23.5	5
Public		ICT	PC	Desktop	8.1	6.2	4
Public		ICT	PC	Laptop PC	8.1	6.2	4
Public		ICT	Mobile	Smart Phone	24	0	3
Public		ICT	Mobile	Phone - not smart	24	0	5
Public		ICT	Tablet	Tablet	24	0	3
Public		ICT	Storage	NAS	1	23	5
Public	Smart Cities	Automation	Street Lights	Street Lights	0	24	10
Public	Smart Cities	Security	Video	IP Camera - Public + Business	24	0	10
Public	Health	Automation	IoT	Sensors: Health - LE	0	24	5
Public	Utilities	Automation	IoT	Smart Meters	0	24	12
Public		ICT	PC	Imaging Equipment	0.5	23.5	5

Table 8 presents the scope of network-connected energy use for each device that is considered additional (due to being connected to a network) and included in the TEM.

Table 8: Network-connected energy consumption scope assumptions

Sector	Segment	Category	Group	Device	Scope of additional energy consumption that is included in the TEM
Residential	Residential	LAN	WAN Access Device	Integrated Access Device	All energy
Residential	Residential	LAN	WAN Access Device	Wired modem	All energy
Residential	Residential	LAN	WAN Access Device	Wireless Modem Router	All energy
Residential	Residential	LAN	Other-Lan	Wireless Router	All energy
Residential	Residential	LAN	Other-Lan	Wired Router	All energy
Residential	Residential	LAN	Other-Lan	Switch	All energy
Residential	Residential	LAN	Other-Lan	Range Extender	All energy
Business		LAN	WAN Access Device	Integrated Access Device	All energy
Business		LAN	WAN Access Device	Wired modem	All energy
Business		LAN	WAN Access Device	Wireless Modem Router	All energy
Business		LAN	Other-Lan	Wireless Router	All energy
Business		LAN	Other-Lan	Wired Router	All energy
Business		LAN	Other-Lan	Switch	All energy
Business		LAN	Other-Lan	Range Extender	All energy
Public		LAN	WAN Access Device	Integrated Access Device	All energy
Public		LAN	WAN Access Device	Wired modem	All energy
Public		LAN	WAN Access Device	Wireless Modem Router	All energy
Public		LAN	Other-Lan	Wireless Router	All energy
Public		LAN	Other-Lan	Wired Router	All energy
Public		LAN	Other-Lan	Switch	All energy
Public		LAN	Other-Lan	Range Extender	All energy

Sector	Segment	Category	Group	Device	Scope of additional energy consumption that is included in the TEM
Residential	Residential	ICT	PC	Desktop	Only network interface energy
Residential	Residential	ICT	PC	Laptop PC	as above
Residential	Residential	ICT	Mobile	Smart Phone	All energy
Residential	Residential	ICT	Mobile	Phone - not smart	Most non-smart phones are for voice and text on 2/3G, impact is minimal
Residential	Residential	ICT	Tablet	Tablet	All energy as almost all applications use the network for services
Residential	Residential	ICT	Storage	NAS	All energy
Residential	Residential	ICT	PC	Imaging Equipment	Only network connection
Residential	Residential	Entertainment	Display	Smart TV	Only network-connected power is additional
Residential	Residential	Entertainment	Audio	AV Receiver	Only network-connected power is additional
Residential	Residential	Entertainment	Audio	AV Speakers	Only network-connected power is additional
Residential	Residential	Entertainment	Audio	Portable Speakers	All energy
Residential	Residential	Automation	Audio	VA Speaker	Always in listening mode (standby), some time in network active
Residential	Residential	Entertainment	Media Device	Games Console	only network connection
Residential	Residential	Entertainment	Media Device	STB & OTT Media Player	All energy, includes the device energy, as primary function is not available if not connected
Residential	Residential	Automation	Lighting	Smart Lights - Wifi	only network connection
Residential	Residential	Automation	Lighting	Smart Lights - LE	only network connection
Residential	Residential	Automation	IoT	Gateway - LE to Wi-Fi	All energy, network active
Residential	Residential	Security	Video	IP Camera - Home	All energy, assume to be in standby state
Residential	Residential	Security	Control	Smart Lock	All energy, assume to be in standby state
Residential	Residential	Automation	IoT	Sensors: Res - LE	All energy, assume to be in standby state
Residential	Residential	Automation	IoT	Sensors: Res - Wi-Fi	All energy, assume to be in standby state
Residential	Residential	Automation	IoT	Blinds + Windows	network energy only, assume to be in standby state
Residential	Residential	Automation	Space Conditioning	Smart Thermostat	All energy, assume to be in standby state
Residential	Residential	Automation	Space Conditioning	Air Conditioners	only network connection
Residential	Residential	Automation	Water Heating	Water Heaters	only network connection
Residential	Residential	Automation	Appliances	Refrigerator	only network connection
Residential	Residential	Automation	Appliances	Freezer	only network connection
Residential	Residential	Automation	Appliances	Washing Machine	only network connection
Residential	Residential	Automation	Appliances	Clothes Dryer	only network connection

Sector	Segment	Category	Group	Device	Scope of additional energy consumption that is included in the TEM
Residential	Residential	Automation	Appliances	Dishwasher	only network connection
Residential	Residential	Automation	Cooking	Oven + Cooktop	only network connection
Residential	Residential	Automation	Cooking	Range Hood	only network connection
Residential	Residential	Automation	Appliances	Small Appliance	only network connection
Business		ICT	PC	Desktop	Only network interface energy
Business		ICT	PC	Laptop PC	as above
Business		ICT	Mobile	Smart Phone	All energy
Business		ICT	Mobile	Phone - not smart	Most non-smart phones are for voice and text on 2/3G, impact is minimal
Business		ICT	Tablet	Tablet	All energy as almost all applications use the network for services
Business		ICT	Storage	NAS	All energy
Business		Security	Video	IP Camera - Public + Business	All energy, assume in active network state
Business	Manufacturing	Automation	IoT	Sensors: Industry - LE	All energy, assume to be in standby state
Business	Manufacturing	Automation	IoT	Gateway: Bus	All energy, network active
Business		Automation	IoT	Comm Building Control	All energy, assume to be in standby state
Business	Retail	Entertainment	Display	Digital Signage Display	only network connection is additional
Business		ICT	PC	Imaging Equipment	only network connection is additional
Public		ICT	PC	Desktop	Only network interface energy
Public		ICT	PC	Laptop PC	as above
Public		ICT	Mobile	Smart Phone	All energy
Public		ICT	Mobile	Phone - not smart	Most non-smart phones are for voice and text on 2/3G, impact is minimal
Public		ICT	Tablet	Tablet	All energy as almost all applications use the network for services
Public		ICT	Storage	NAS	All energy
Public	Smart Cities	Automation	Street Lights	Street Lights	only network connection is additional
Public	Smart Cities	Security	Video	IP Camera - Public + Business	All energy, assume in Active state
Public	Health	Automation	IoT	Sensors: Health - LE	All energy
Public	Utilities	Automation	IoT	Smart Meters	Only Network connection
Public		ICT	PC	Imaging Equipment	Only Network connection

Appendix B: Model Output tables

The output tables for the TEM are provided as a separate excel file, and include

- Total edge device network-connected energy consumption by category, group and device 2010 - 2030
- Network standby energy consumption by category, group and device 2010 – 2030
- Network active energy consumption by category, group and device 2010 – 2030
- Upstream energy consumption by category, group and device 2010 – 2030
- Total stock by category, group and device 2010 – 2030

A summary of the detailed outputs are provided in the following tables.

Network-connected energy consumption by state and upstream energy consumption (TWh)

Year	Network Active	Network Standby	Upstream
2010	85	13	370
2011	99	21	406
2012	111	32	452
2013	124	47	441
2014	137	64	432
2015	163	83	417
2016	184	103	417
2017	200	122	408
2018	213	140	396
2019	225	156	379
2020	236	170	360
2021	247	184	350
2022	260	200	344
2023	273	215	351
2024	285	232	357
2025	297	248	362
2026	309	261	359
2027	320	272	355
2028	330	281	353
2029	341	289	351
2030	351	296	351

Network-connected consumption by category, split by edge device and upstream component (TWh)

Year	LAN		Automation		Entertainment		ICT		Security		Total	
	Edge Device	Upstream	Edge Device	Upstream	Edge Device	Upstream	Edge Device	Upstream	Edge Device	Upstream	Edge Device	Upstream
2010	75	0	4	0	2	4	17	367	0	0	98	370
2011	85	0	7	0	8	8	19	398	0	0	120	406
2012	93	0	11	0	16	37	23	412	1	2	143	452
2013	100	0	16	0	26	64	27	372	1	4	171	441
2014	106	0	23	0	38	90	32	336	1	6	201	432
2015	126	0	31	0	52	113	36	297	2	8	246	417
2016	140	0	40	0	64	139	38	269	3	9	286	417
2017	152	0	49	0	76	133	40	263	5	11	322	408
2018	159	0	59	0	85	127	42	256	7	13	353	396
2019	165	0	69	0	93	119	44	246	9	15	380	379
2020	171	0	79	0	99	111	45	234	11	16	406	360
2021	177	0	91	0	103	105	46	227	14	18	432	350
2022	184	0	106	0	107	102	47	223	16	19	460	344
2023	190	0	124	1	109	102	48	228	18	21	488	351
2024	195	0	143	1	110	102	48	231	21	23	517	357
2025	200	0	162	1	111	102	49	235	24	25	545	362
2026	204	0	179	1	110	100	50	232	27	26	570	359
2027	208	0	193	1	110	97	50	230	30	28	592	355
2028	212	0	205	1	109	95	51	228	34	29	611	353
2029	217	0	216	1	108	93	51	227	37	31	630	351
2030	221	0	226	1	108	91	51	226	41	32	647	351

Appendix C: Detailed sources of information for the TEM

Global Multi Product Forecasts

Energy

IT sector's electricity breakdown worldwide by component 2017 | Statistic
URL: https://www.statista.com/statistics/683233/electricity-components-of-the-global-it-sector-by-component/ accessed 30/4/18

IEO2017 - International Energy Outlook 2017- U.S. Energy Information Administration
URL: https://www.eia.gov/outlooks/ieo/pdf/0484(2017).pdf accessed 30/4/18

Data Forecasts

Cisco: Live Video to Increase 15x to 13% of All Video Traffic By 2021 - VideoNuze
URL: http://iq.videonuze.com/article/cisco-live-video-to-increase-15x-to-13-of-all-video-traffic-by-2021/?print=true accessed 10/5/18

The Zettabyte Era: Trends and Analysis - Cisco
URL: https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/vni-hyperconnectivity-wp.html accessed 12/5/18

Cisco 2011: Global Internet Traffic Projected to Quadruple by 2015 | The Network
URL: https://newsroom.cisco.com/press-release-content?articleId=324003 accessed 2/6/18

State of the IoT 2018: Number of IoT devices now at 7B – Market accelerating
URL: https://iot-analytics.com/state-of-the-iot-update-q1-q2-2018-number-of-iot-devices-now-7b/ accessed 3/9/18

Point Topic – World Broadband Statistics – Q1 2018
URL: http://point-topic.com/free-analysis/world-broadband-statistics-q1-2018/ accessed 4/9/18

All Products Forecast

Measuring the Strategic Value of the Internet of Things for Industries
URL: https://www.gartner.com/doc/3299317?srcId=1-7389946276&stl=0 accessed 30/3/18

The Internet of Things: Consumer, Industrial & Public Services
URL: https://www.juniperresearch.com/researchstore/iot-m2m/internet-of-things/consumer-industrial-public-services-(1) accessed 15/8/18

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